Volume 9 Number 6

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

SEPTEMBER 1925

WATER ANALYSES IN OIL PRODUCTION AND SOME ANALYSES FROM POISON SPIDER, WYOMING[1]

E. M. PARKS
Denver, Colorado

ABSTRACT

The use of water analyses in determining the source of oil-field waters is urged. The meaning of analyses and the different methods of graphic statement are illustrated. A new form of graph believed to be clearer and simpler to use is suggested. As an example of the use of water analysis, nineteen water analyses from the Tensleep, Dakota, Morrison, and Sundance sands of South Casper Creek, Poison Spider, and Notches, Wyoming, are tabulated and studied graphically; the conclusion being that the waters are distinguishable from analyses. The geochemical relations between oil and water are briefly reviewed.

The greatest single problem in developing or producing oil is to exclude water from the oil sands. There are so few cases where water actually aids recovery that they are exceptional. In repairing a bad water condition it is necessary to determine the source of the water first of all. Most water troubles in producing oil fields are caused by top waters entering the oil sands either in the particular well giving the trouble or else from nearby holes. If the water enters the sands from other holes than the one yielding water, a comprehensive study of all the known water conditions and the method of finishing and the state of repair of a whole group of wells must be undertaken. The complete history of all the wells in a neighborhood should be known and a continuous record of the mechanical conditions of the wells must be available to avoid unnecessary expense.

A file of water analyses, if the sources of the samples are known

[1] Read by title before the Wichita meeting, 1925.

and if the analyses are correct, is probably of more assistance than any other class of facts in the location of the source of invading water. These analyses should, by all means, be obtained while developing the field. When new water is struck in drilling, it should be sampled and analyzed. The sample should be taken as soon as the water is encountered and not after drilling ahead, since a different water may be met, or it may change in chemical character if allowed to run down several hundred feet of open hole. One should not be content with analysis of the waters from only two or three wells, for there may be local variations in the same water stratum, and until uniformity of chemical characters is established by several analyses or the local variations determined, it is unsafe to draw conclusions.

STATEMENT OF WATER ANALYSES

The burden of interpreting water analyses necessarily falls on geologists, many of whom have paid little attention to the study of water analyses. No great store of chemical knowledge is needed if the problem is properly approached. Every geologist knows what "strong alkalies," "alkaline earths," "strong acid radicals," "weak acid radicals," "ions," and "reacting values" mean in a general way. If comparisons of several analyses are to be made, they must be made on a chemical basis. The proportions of the various ions do not react in proportion to the various weights as stated in parts per million, but in proportion to their "capacity for reaction," or "reaction value," or "chemical equivalence." The reacting value of each ion is determined by multiplying the amount of each radical by weight (or in parts per million) by its "reaction coefficient," which is the valence of the radical divided by the atomic weight of the given radical.[1] If the analysis is stated in oxides of the various bases,

[1] Reacting value equals parts per million multiplied by reaction coefficient.

The reaction coefficient is valence divided by atomic weight and the following table gives the coefficient for the ions determined in water analysis:

*Sodium (Na)	0.0434	Sulphate (SO_4)	0.0208
*Potassium (K)	.0256	Chloride (Cl)	.0282
Calcium (Ca)	.0499	Nitrate (NO_3)	.0161
Magnesium (Mg)	.821	Carbonate (CO_3)	.0333
Hydrogen (H)	0.992	Bicarbonate (HCO_3)	.0164
		Sulphide (S)	0.0622

The asterisk (*) means that when sodium and potassium are not separated in analysis, the reaction coefficient of sodium is used in calculating the reacting value

it must first be recalculated to eliminate the oxygen. This is elementary but no apology need be made, for many analyses are still sent out from the laboratories in forms that do not allow chemical comparisons to be made until they are recalculated. Many commercial chemists would rather perform an analysis than make the calculations needed for a statement of real chemical significance. After the reacting values are determined they should be reduced to a percentage basis, for comparison of waters is then easier than if concentration is not eliminated. The true chemical character of the water now begins to appear. These calculations can be made by following directions given by Rogers,[1] Palmer,[2] or Stabler.[3]

The analyses can be studied and compared without further rearrangement, and they can be plotted on significant graphs, which are a great help in comparing several analyses. Some of the graphs are cited later. No theoretical assumptions are involved in comparing percentage reacting values of ions as it is the simplest possible basis of comparison. The form of statement cited in the next paragraph is objected to by some as being artificial even if it does bring out important practical and chemical differences in ground waters. In oil-field work our interest is usually directed toward distinguishing analyses, and the writer has found that comparisons made by graphs of reaction values in percentage are adequate for the purpose and that the reaction properties are not absolutely necessary. Once the reaction values in percentage are calculated, the reaction properties are easily obtained, and a new form of graph suggested enables one to deduce the reaction properties easily.

---

since potassium is much less than sodium. The error is considerable and tends to increase the reacting value of the strong alkalies above what it should be. In river waters the sodium is usually three to four times as abundant as potassium, and in sea waters thirty times. Average ground waters would fall between these two extremes, probably the sodium would run over twenty times the potassium in the average oil-field water. The error is appreciable but would hardly ever vitiate conclusions. In general, it indicates a water as more alkaline than it really is and decreases secondary salinity.

[1] G. Sherburne Rogers, "Chemical Relations of the Oil Field Waters in San Joaquin Valley, California," *U. S. Geol. Survey Bull. 653* (1917), pp. 34–37.

[2] Chase Palmer, "The Geochemical Interpretation of Water Analyses," *U. S. Geol. Survey Bull. 479* (1911), pp. 8, 12–14.

[3] Herman Stabler, "The Industrial Application of Water Analyses." *U. S. Geol. Survey Water-Supply Paper 274* (1911), p. 165 ff.

REACTION PROPERTIES

After the reacting values of ions in percentage are obtained, the reacting properties of the water may be calculated from the reacting values. The use of these reacting properties was first proposed by Chase Palmer. The properties called "primary" result from combination of the strong alkalies (Na and K) with either the strong acid radicals (SO_4 and Cl) or the weak acid radicals (CO_3, HCO_3, and S). The salts resulting from combination of the strong alkalies and the strong acids are called "primary salts."

1. *Primary salinity* = "rSO_4" + "rCl" + *equal value* "rNa" + "rK." —In this equation r is the reacting value of the radicals in percentage. All natural waters show primary salinity, and the remaining properties of the water will depend on whether the strong alkalies or the strong acids are in excess. Two cases therefore result.

If the strong acids are in excess we have:

2. *Secondary salinity = excess of* "rSO_4" + "rCl" + *equal value of* "rCa" + "rMg."—These salts are stable but not quite so stable as the primary salts. They impart permanent hardness to a water.

If the strong alkalies, instead of the strong acids, are in excess, and entirely different water results; and we have:

3. *Primary alkalinity = excess of* "rNa" + "rK" + *equal value of* "rCO_3" + "$rHCO_3$" + "rS."—The water is soft. The bicarbonates usually exceed the carbonates, and the sulphates are generally low. The water contains OH because of hydrolysis.

If a water has secondary salinity but not enough of the strong acids present to balance the alkaline earths (Ca and Mg), the excess of alkaline earths will be balanced by carbonates. This alkalinity is called:

4. *Secondary alkalinity = excess* "rCa" + "rMg" *over* "rSO_4" + "rCl" *with equal value of* "rCO_3" + "$rHCO_3$."—All of these properties are stated in percentage. Since all ground waters show primary salinity while a water cannot show both secondary salinity and primary alkalinity, the foregoing classification divides water into two contrasting groups which present important practical and chemical differences.[1]

[1] Acid waters are known, also, in some mines and volcanic regions, but are not met in oil fields. In Palmer's classification they are called "tertiary saline waters."

ERRORS IN ANALYSES

In water analysis, bicarbonate is often not determined, and it is assumed that an excess of strong alkalies over strong acids must be balanced by bicarbonate. Similarly, the excess of alkaline earths over strong acids is assumed to be balanced by bicarbonate. The bicarbonate is therefore determined by difference and not by actual analysis. This is important to remember, because if part of the strong alkalies (Na and K) are lost in evaporation during analysis, the carbonates will be too low, and a primary alkaline water will appear in the analysis as lower in primary alkalinity than it actually is, or even appear as a secondary saline water. This is the commonest error in water analysis. The strong alkalies (sodium and potassium) usually are determined together because of the labor involved in separating them. Many chemists employ the foregoing method for determining carbonates and calculate the whole analysis on that basis, but state elsewhere in the analysis the amount of bicarbonates as determined independently by titration. In that case, if one wishes to check the accuracy of the alkali determination, it can be done by calculating the reacting value of the carbonates obtained by titration and comparing it with the reacting value stated in the analysis which was obtained by the difference. Two instances of this occur in the analyses in Table I. The concentration of analyses 15, 16, 17, 18, and 19 are about the same, and the bicarbonates calculated as $CaCo_3$ (obtained by titration) are nearly proportional. In the analyses, as stated, only a trace of bicarbonate appears in 16 and 19. Mr. Updegraff notes, therefore, that some alkali must have been lost in analysis. These two waters (16 and 19) are really higher in strong alkalis and primary salinity and lower in secondary salinity than shown by analysis and should show secondary alkalinity, and the five Tensleep waters would be grouped more closely on Fig. 1 than they actually appear.

In many analyses it is impossible to determine the error at all. Unless all the important radicals are determined directly, or unless there are some independent determinations by different methods, there may be sufficient error to prevent geologic conclusions. If all the important radicals (Na+K, Ca, Mg, SO_4, Cl, CO_3, HCO_3) have been directly determined, the accuracy of the analysis is

easily checked, because the sum of the reacting values of the bases in percentage must equal the sum of the reacting values of the acids in percentage. The difference will be due to error in analysis, to ignoring the rôle of SiO_2, Al_2O_3, and Fe_2O_3 in combination with other radicals, and to calculating potassium as sodium. If the bases and acids balance exactly in an analysis, if is a fair inference that certain ions were obtained as differences, and we have no check on the accuracy of the analysis.

As regards SiO_2, there are differences of opinion, some holding that silicic acid is actually present in many cases, others that it is colloidal silica. In analysis it is arbitrarily assumed to be colloidal silica. In general, alkaline waters contain more silica, as noted by Palmer[1] and others.[2] No important conclusions can be based on the silica.

Iron oxide and alumina are determined together usually and are likewise assumed to be colloidal and not taken account of in the reaction properties. The nature of the iron compounds in ground waters is not well known.

Hydrogen sulphide is an important constitutent of ground waters but it requires extranordinary care in sampling and immediate analysis to determine, or else collection of an extra sample in a bottle containing a little cadmium chloride to fix the sulphur.

GRAPHIC METHODS OF COMPARING WATER ANALYSES

After computing the reacting values of the ions in percentage (and the reaction properties of the waters in percentage if desired), the next step is to plot the analysis of each water on a suitable graph. Three different methods of graphic study are illustrated, and a fourth cited.

The form of chart (Fig. 1) used to represent graphically the reaction properties of several analyses on one chart was suggested by Rogers.[3] It shows up many chemical facts regarding water analyses on a single chart. It is based on the reaction properties and sulphate-

[1] Chase Palmer, *op. cit.*, pp. 22, 27.

[2] F. W. Clarke, "Data of Geochemistry," *U. S. Geol. Survey Bull. 695*, pp. 107, 205; *Bull. 770* (1924), pp. 111, 211.

[3] G. Sherburne Rogers, *op. cit.*, p. 54.

chloride ratio. Waters with secondary salinity fall to the left of the vertical line, waters with primary alkalinity to the right. Waters high in chloride fall near the bottom of the chart, those high in sulphate fall nearer the top. For the geologist this chart is of great use in studying waters, especially if it is adapted to show concentration in parts per million.

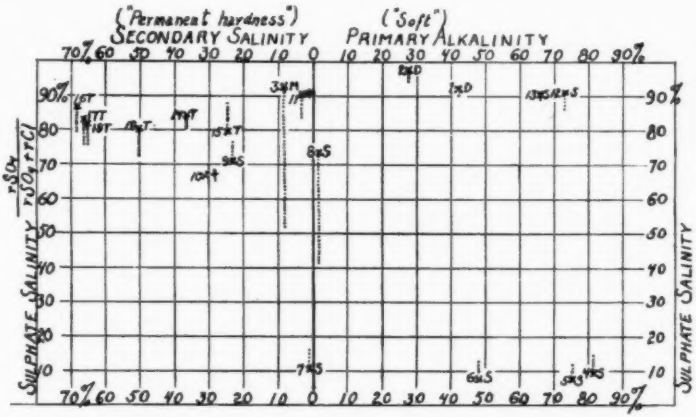

("Permanent hardness")
SECONDARY SALINITY
("Soft")
PRIMARY ALKALINITY
70% 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90%
90% 80 70 60 50 40 30 20 10
SULPHATE SALINITY — rSO4 / rSO4+rCl
SULPHATE SALINITY

FIG. 1.—Numbers refer to analyses in Table. Letter indicates geologic horizon

D=Dakota M=Morrison S=Sundance T=Tensleep

Each dot indicates 500 parts total solids per million

✱ No. 11 probably due to mixture of water from Morrison and Dakota

† Drip on gas line from well producing some water, sample No. 6

This graph does not always serve to distinguish waters which are unlike; it does not afford any comparison based on secondary alkalinity or on the ratio of carbonates to sulphate. Two waters may show the same secondary salinity and yet differ greatly in the relative proportions of the bases ($rNa+rK$ and $rCa+rMg$). As illustration of this, samples 9 and 15 fall close together in Figure 1 but are quite different.

Another method of graphic representation of water analyses (Fig. 2), devised by F. G. Tickell,[1] is employed by the California

[1] M. A. Grizzle, "Geochemical Relationship of Waters Encountered in the Huntington Beach Field," *California State Min. Bur.*, Vol. 9, No. 6 (1923), p. 17.

State Mining Bureau and by some oil companies. An irregular, star-shaped figure of each analysis is constructed by plotting the reacting values in percentage of the various radicals on radial lines and joining the intercepts on adjacent radii. This method has a great deal of merit and will serve to distinguish waters that fall close together on Rogers' chart if they are chemically different. The graph of sample 15 (Fig. 2) is quite different from that of sample 9, which falls rather near the Tensleep waters on Rogers' chart (Fig. 1). In order to illustrate the method, a few other samples are plotted in Figure 2.

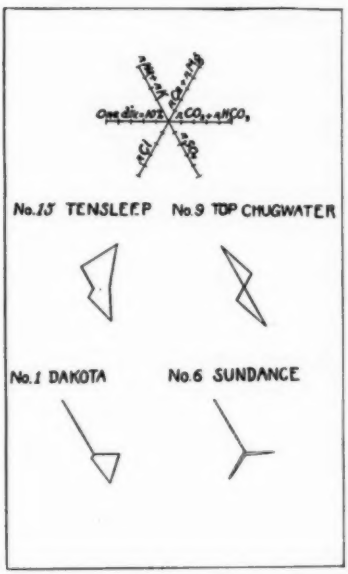


FIG. 2.—Examples of graphic water analyses (co-ordinates after F. G. Tickell).

The writer wishes to suggest another graphic method (Fig. 3) based on the following considerations: (1) equal areas of positive and negative radicals, (2) sulphate and chloride salinity ratios easily compared by inspection, (3) carbonate ratio apparent by inspection, (4) chemically similar waters with similarly shaped graphs, (5) primary alkaline or secondary saline water inferred by inspection, (6) percentage of reacting values. This graph is compact, easily prepared on any rectangular co-ordinate paper, and its meaning is easily grasped (see Fig. 3). One can also form a fair idea of what chemical compounds will be present in the water. By using a different pattern for calcium and magnesium, every possible comparison that the chemical analysis itself allows can be made. This graph does not emphasize primary alkalinity and secondary salinity although the reaction properties are easily inferred from the areas of the different radicals, and it is merely a visual presentation of the most important chemical constituents reduced to their chemical equivalence. Other radicals

can be included if desired. The bases are all grouped together, with the strong alkalies to the left of the vertical median line, and the alkaline earths to the right. The strong acids are grouped together above the bases, with chloride on one side and sulphate on the other side of the vertical line. The carbonates are grouped together and placed to the right. A little practice will enable one to tell at a glance whether the water shows primary alkalinity or secondary salinity, but the reaction properties are not the basis of the graph. The concentration in parts per million can be written in the upper left-hand corner.

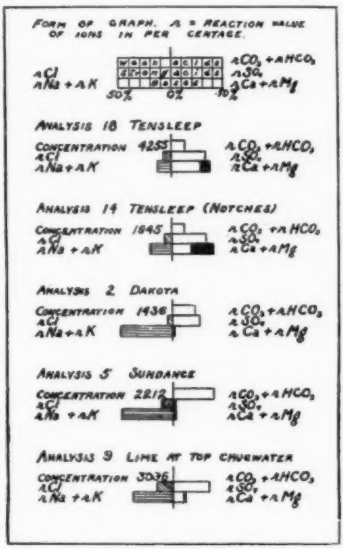


FIG. 3.—Proposed graphic method of representing water analyses.

The graph is similar to Tickell's in meaning, but shows equal areas of bases and acids and is easier to construct without special paper.

This method is different from one proposed by Collins,[1] as he uses reaction values which have not been reduced to a percentage basis. Collins' diagrams involve concentration by total areas of reaction values.

CHEMICAL RELATION OF OIL AND GROUND WATERS

Before discussing the analyses tabulated, a brief résumé of certain tentative principles stated by Rogers[2] regarding chemical relations of the oil-field waters of San Joaquin Valley, California, should

[1] W. D. Collins, "Graphic Representation of Water Analyses," *Ind. and Eng. Chemistry*, Vol. 15 (1923).

[2] G. S. Rogers, "Chemical Relations of the Oil Field Waters in San Joaquin Valley, California," *U. S. Geol. Bull. 653* (1917); "Sunset-Midway Oil Field, California," *U. S. Geol. Survey Prof. Paper 117*, Part II, "Geochemical Relations of the Oil, Gas and Water" (1919).

be noted, since similar or equally important principles undoubtedly apply in other regions. He found, in general, that the surface waters of the San Joaquin Valley are high in sulphate as compared to chloride, and that they are always secondary saline waters rather than primary alkaline and low in bicarbonate. As the depth increases, there is a decrease in secondary salinity, and finally primary alkalinity appears. Waters above the oil zone commonly show hydrogen sulphide, due almost certainly to deoxidation of sulphates by hydrocarbons, which decreases the sulphate and increases carbonates. Waters closely associated with hydrocarbons are generally low in sulphate, occasionally sulphate-free,[1] and are generally high in carbonates, and the increase in carbonates is both relative and absolute as the oil is approached. The oils which are closely associated with water are generally heavier and higher in sulphur (and presumably oxygen, also) than those not close to water. In a word, the oil is oxidized and sulphur compounds are formed and the oil becomes heavier because of the chemical changes as well as because of the escape of the more volatile and soluble constituents; the waters have been robbed of sulphate and carbonates have been formed. Rogers believes that devolatilization is a minor factor in increasing the gravity. Chloride becomes relatively and absolutely more important in waters in the oil zone, doubtless due to residual chloride from original chlorides present in sea water, waters above being measurably freshened by greater circulation.

In all of Rogers' discussion, which is too compact and important to be easily summarized here, he has emphasized the alteration of waters in proximity to hydrocarbon accumulations. Although very little experimental evidence of direct bearing can be cited, he concludes that reduction of sulphate by hydrocarbons, with formation of hydrogen sulphide and carbonates in the water, and sulphur and oxygen compounds in the oil, takes place. His conclusions regarding sulphate and carbonates of oil-field waters are probably of wide application.

In other oil fields where the climate is not so dry, surface waters may show entirely different characters. In these regions probably concentration will be relatively more important in studying waters,

[1] See 4, 5, and 6 of Fig. 1, waters from Sundance gas sands.

and the chloride and sulphate ratios will be the important constituents to fix on in studying the waters of oil fields, and carbonate ratios less important.

A similar alteration in ground waters in the Lance formation involving reduction of sulphates and formation of carbonates by reaction between methane and sulphate has recently been discussed by Renick,[1] and several analyses of artesian water are cited. In this case he supposes that methane derived from lignitic fragments is the immediate cause of reduction of sulphate, since the wells showing methane yield least sulphate. Rogers,[2] however, attributes the reaction in the case of San Joaquin Valley oil-field waters to less stable hydrocarbons than methane.

It is generally supposed that the alkaline earths are especially characteristic of surface waters and that deeper waters show strong alkalies in greater proportions. This means a decrease of secondary salinity and finally a development of primary alkalinity. Downward-percolating waters probably exchange the calcium and magnesium which characterize surface waters for sodium and potassium. In another article Renick[3] brings together the theoretical and experimental evidence in favor of this and cites field evidence for it. This is supposed to take place by exchange of bases with certain special clays. Clarke[4] cites evidence that surface waters lose potassium in percolating through clays.

However, every problem of oil-field waters is yet more or less a case by itself. Most of the analyses available for study are from the oil fields, and most of these analyses are of waters above the oils. Before we know a great deal about general chemical relations of oil-field waters we need many analyses from regions outside the oil fields, and of waters below the oil zones. Analyses of samples from wildcat wells and from wells drilled into bottom waters are therefore

[1] B. Coleman Renick, "Some Geochemical Relations of Ground Water and Associated Natural Gas in the Lance Formation, Montana," *Jour. Geol.*, Vol. 22 (1924), pp. 568–85.

[2] G. Sherburne Rogers, *Prof. Paper 117*, Part II, p. 28.

[3] B. Coleman Renick, "Base Exchange in Ground Water by Silicates as Illustrated in Montana," *U. S. Geol. Survey Water Supply Paper 520-D* (1924).

[4] F. W. Clarke, "Data of Geochemistry," *U. S. Geol. Survey Bull. 695* (1920), p. 206; *Bull. 770* (1924), p. 212.

of particular value. Freedom of circulation in continuous porous sands like the Dakota and Tensleep, and the chemical character of the rocks, like the gypsum and salt in the red beds, will doubtless prove as important in determining chemical characters as proximity to oil and gas.

None of the reactions mentioned affect chloride, and it is therefore one of the best constituents for distinguishing waters.

AN APPLICATION OF THE STUDY OF WATER ANALYSES

The writer was asked to determine the source of water which had developed in five wells producing oil from the Tensleep sand in South Casper Creek field, 22 miles northwest of Casper. One well struck bottom water in drilling and had been plugged back but the water never entirely shut off; the other four wells were at first quite free from water. Wells on two neighboring and apparently equally good folds found water in the Tensleep, one of them with a show of oil. This field is one of the few promising places where the Tensleep has produced oil thus far. At Notches, about 40 miles northwest of Casper, a well struck oil in the Tensleep and flowed about five hundred barrels for several weeks but finally developed water.

In the South Casper Creek field there is no gas with the oil in the Tensleep. Above the Tensleep the Sundance is productive of considerable gas in three sands with a narrow rim of oil around the gas. Water has been struck in several Sundance wells, especially in the lowest sand, and in a line at the top of the Chugwater below the gas sands. Water is also found in small amounts in the Morrison above the Sundance; in moderate amounts in the "Lakota," but apparently not in all wells; and in large amounts in the Dakota. Some water in small amounts is also found in the shallow Wall Creek sands.

WATER HORIZONS IN SOUTH CASPER CREEK AND POISON SPIDER DOMES

1. Lower Wall Creek: Small amounts of water at shallow depths. No analysis available.
2. Dakota: Large amounts of soft alkaline water, which rises to about 5,500 feet elevation (250± feet below surface). Analyses 1 and 2.
3. "Lakota": Not recognized in all logs. Apparently a thin, close-pored sand.

Small amount of water of lower head than Dakota water. No analysis available.

4. Morrison: Sandy shale or shaly sand with small amount of very concentrated water. Head not known. Analysis 3.
5. Sundance: Three separate gas sands. Water in all these sands outside gas area and oil in a few wells. Lowest sand carries water oftener than the others. Analyses 4, 5, and probably 6, 7, 8, and 12, also.
6. Lime: At base of Sundance or top of Chugwater with small amount of water in some wells but not in all. Water strings of wells to Tensleep commonly landed in this lime. Water resembles Tensleep below somewhat, but distinguishable in analyses. Head not known. Analysis 9.
7. Tensleep: Flowing water in one well on neighboring structure. Tensleep is 400± feet thick with oil in five wells, one of which reached bottom water, one other well with water and show of oil. Water has developed in all the wells. Analyses 15, 16, 17, 18, 19.

After landing the second water string below the Sundance with enough cement to shut off the gas sands, the Dakota water string is usually pulled.

Very few analyses were available, and comparatively little could be learned about the wells. Fourteen samples of water were collected during the study, and a few other good analyses were obtained and are tabulated in Table I and also shown in Figure 1. The source of two samples from the Dakota (1 and 2), one from the Morrison (3), one from the Lower Sundance (4 and 5), and one from the lime at base of Sundance (9) is definitely known. Of the remaining samples, 6, 7, 8, and 12 are very probably from the Sundance, but as they were obtained after the wells were finished, there is some doubt. Samples 13 and 14 are from Notches dome, and the source of each is known. The source of samples 15, 16, 17, 18, and 19 was to be determined. All the samples were collected with care and analyzed by S. Updegraff in the Standard Oil Laboratory at Casper, immediately after collecting.

When these analyses are studied in Figure 1 it is seen at once that only five analyses bear any similarity to the five Tensleep waters. The latter are all high in secondary salinity and in sulphate salinity and show moderate concentration. The high sulphate salinity and the large amount of alkaline earths both relatively and absolutely indicate possibly that the Tensleep water is of surface origin rather than connate, and reached its present position by circulating down-

ward from the outcrop, for the Tensleep is one of the main artesian water sands over an enormous area. The analyses of Tensleep waters resemble one another so closely in every respect that the waters are evidently of the same origin. If they could not have originated from the top waters they must be native to the Tensleep sand.

Sample 10 is from the drip on the gas line from the same well from which sample 6 was pumped. It is very low in concentration (117 parts per million) and of quite different character from 6. These two analyses prove to the writer that samples taken from a drip are not to be relied on in determining character of the waters in the well. It has therefore no bearing on the source of Tensleep water.

Sample 11 was taken from a well to the Sundance soon after cementing. Water from Dakota (1) and Morrison (3) had stood in the hole for some time before cementing. This water was later exhausted, and it appears to be what would result from diluting the very concentrated Morrison water (3) by the Dakota water (1).

Sample 9 is from a lime at the base of the Sundance or top of the Chugwater. Water strings in the wells to the Tensleep sand are usually landed in this lime, which is reported not to yield water in some wells and in others yielded about three bailers per hour. It is, however, the most probable source of the water in the Tensleep oil wells, if the water comes from above at all, since some of the water strings are landed in the top of the lime. In two cases they had to free the casing and land lower down in the lime to get a shutoff. This water is similar in concentration to the Tensleep waters but is much higher in alkalies and lower in alkaline earths, both relatively and absolutely. The difference does not show up strikingly in Figure 1, and that chart is therefore mainly of service in further comparison of the analyses. It is readily distinguishable in other graphs (Figs. 2 and 3). It is concluded that this water could not be the source of the water in the oil wells, for if we suppose it comes from the lime we must account for a decrease in alkalies and an increase in alkaline earths, the water in the lime is high in sodium sulphate while the Tensleep waters are high in calcium sulphate. While calcium sulphate might be increased by solution of gypsum from the Chugwater, there is no apparent reason why the sodium should be decreased.

Sample 8 is from a gas well in the Sundance producing gas and

TABLE I

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Field	South Casper Cr.	Poison Spider	South Casper Cr.	Poison Spider	Poison Spider	Poison Spider	South Casper Cr.	Poison Spider	Poison Spider	Poison Spider	Poison Spider	South Casper Cr.	Notch-es	Notch-es	South Casper Cr.	South Casper Cr.	South Casper Cr.	South Casper Cr.	South Casper Cr.
Location	3–93–83	12–33–83	3–33–83	7–33–82	7–33–82	12–33–83	11–33–83	12–33–83	12–33–83	12–33–83	1–33–83	33–34–83	10–37–85	10–37–85	3–33–83	3–33–83	3–33–83	3–33–83	3–33–83
Sand	Da-kota	Da-kota	Morri-son	Sun-dance	Sun-dance	Sun-dance	Sun-dance?	Sun-dance	Sun-dance	Sun-dance	Sun-dance?	Sun-dance	Sun-dance	Ten-sleep	Ten-sleep	Ten-sleep	Ten-sleep	Ten-sleep	Ten-sleep
Properties of reaction in percentage:																			
Primary salinity	58.0	69.2	91.6	18.8	22.0	52.0	97.16	92.8	76.8	27.2	94.72	25.4	33.2	40.6	24.8	31.6	24.6	26.4	34.6
Secondary salinity	.....	.....	8.4	.....	.....	.....	.94	.....	23.2	31.6	3.18	.....	.....	36.6	50.2	68.4	66.4	50.4	65.4
Primary alkalinity	42.0	27.2	.....	81.2	75.4	48.0	.....	1.6	.....	.....	.....	73.0	66.8	.....	.....	.....	.....	.....	.....
Secondary alkalinity	.....	3.6	.....	.....	2.6	.....	1.86	5.6	.....	41.2	1.58	1.6	.....	22.8	25.0	.....	9.0	23.2	.....
Sulphate salinity	92.1	97.7	92.6	9.6	7.3	7.7	10.3	73.4	70.6	66.7	90.21	91.0	90.8	84.2	79.2	86.8	82.9	80.0	81.8
Constituents in parts per million:																			
Sodium (Na) } Potassium (K) }	296	427	6,140	745	667	884	963.9	5,210	806	10	1105.7	757	394.3	264	335	330*	331	374	392*
Calcium (Ca)	Trace	9	245	.....	10	Trace	29.32	125	185	19	22.2	11	.....	208	722	558	660	704	565
Magnesium (Mg)	Trace	4	146	.....	3	Trace	.....	88	17	2.5	6.1	Trace	.....	77	111	73	139	126	47
Iron (Fe)	.....	.....	.....	.....	Trace	Trace	.....	.....	Trace	Trace	.....	Trace	.....	.....	.....	.....	.....	.....	.....
Aluminum (Al)	.....	.....	.....	.....	Trace	Trace	.....	.....	Trace	Trace	.....	Trace	.....	.....	.....	.....	.....	.....	.....
Sulphate (SO_4)	333	627	12,946	41	22	72	280.71	7,900	1,546	30	2212.8	368	251.0	882	1,705	1,893	2,151	1,824	1,933
Chloride (Cl)	22	11	753	196	215	650	1347	2,115	474	11	177.3	29	17.5	122	333	311	310	340	314
Carbonate (CO_3)	30	31	.....	Nil	134	60	25	.....	.....	.....	24.0	.....	.....	.....	.....	.....	.....	.....	.....
Bicarbonate (HCO_3)	265	301	.....	1,588	1,145	1,009	.....	1,076	.....	39	.....	1,514	343.0	392	915	Trace*	323	871	Trace*
Silica (SiO_2)	18	26	Trace	16	16	15	.....	52	8	6	.....	Trace	.....	.....	26	24	4	16	Trace
Total	964	1,436	20,230	2,586	2,212	2,690	2,646	16,566	3,036	117.5	3,548	2,679	1,006	1,945	4,147	3,189	3,918	4,255	3,251

1. Fargo Oil Co. Southwest of four water wells in Dakota. Collected by E. M. Parks. Analyzed by S. Updegraff.

2. New York Oil Co. Dakota water well near Gordon 6. Collected by E. M. Parks. Analyzed by S. Updegraff.

3. Fargo Oil Co. No. 20. Drilling. Water from bailer. Three bailers per hour. Same water struck in several wells. Coll., E. M. P. Analyst, S. U.

4. Miles Oil Corp. No. 1. Oil and some gas in upper Sundance, water in lower Sundance. Collected by Mr. Kimberling, analyzed by U. S. Bureau of Mines.

5. Miles Oil Corp. No. 1. Same water collected by E. M. P. eight weeks later than sample 4. Analyst, S. U.

6. New York Oil Co. Gordon 7. Gas well pumped every few days to remove water, which is probably from Sundance. Coll., E. M. P., Analyst, S. U.

7. New York Oil Co. No. 4. Gas well (?). From pump. Collected by F. A. Lichtenheld, analyzed by U. S. Bureau of Mines (W. B. L.).

8. New York Oil Co. Gordon 1. Gas with little oil and water. First well on lease. Water probably from Sundance. Sampled from tank by E. M. P., Analyst, S. U.

9. New York Oil Co. Gordon 10. Drilling well. Water from lime below Sundance sands. Yield three bailers per hour. Water strings commonly landed in this lime which apparently does not carry water in all wells. Collected by Mr. Young, analyzed by S. U.

10. New York Oil Co. Gordon 7. Same well as sample 6. This water from drip on gas line while sample 6 is from pump. Note difference in waters. Coll., E. M. P., Analyst, S. U.

11. Fargo Oil Co. Weathers 3. Gas well in Sundance. From bailer after cementing. Source uncertain because water exhausted after cementing, it may be a mixture of Dakota (2) and Morrison (3) water.

12. New York Oil Co. Townsend 5. Gas well in Sundance. Sampled by Mr. Young while blowing off water. Analyst, S. U.

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Field	South Casper Cr.	Poison Spider	South Casper Cr.	Poison Spider	Poison Spider	Poison Spider	South Casper Cr.	Poison Spider	Poison Spider	Poison Spider	Poison Spider	South Casper Cr.	Notch-es	Notch-es	South Casper Cr.	South Casper Cr.	South Casper Cr.	South Casper Cr.	South Casper Cr.
Location	3–93–83	12–33–83	3–33–83	7–33–82	7–33–82	12–33–83	11–33–83	12–33–83	12–33–83	12–33–83	1–33–83	33–34–83	10–37–85	10–37–85	3–33–83	3–33–83	3–33–83	3–33–83	3–33–83
Sand	Da-kota	Da-kota	Morri-son	Sun-dance	Sun-dance	Sun-dance	Sun-dance?	Sun-dance	Sun-dance	Sun-dance	Sun-dance?	Sun-dance	Sun-dance	Ten-sleep	Ten-sleep	Ten-sleep	Ten-sleep	Ten-sleep	Ten-sleep
Reacting values in percentage:																			
Alkalies																			
Sodium (rNa) +potassium (rK)	50.0	48.2	45.8	50.0	48.7	50.0	48.56	47.2	38.4	13.6	47.36	49.2	50.0	20.3	12.4	15.8	12.3	13.2	17.3
Alkaline earths																			
Calcium (rCa)	.....	1.0	2.1	.....	.8	.....	1.40	1.3	10.1	30.1	1.09	.8	.....	18.4	30.0	27.6	27.9	28.5	28.8
Magnesium (rMg)	.....	.8	2.1	.....	.5	.....	.....	1.5	1.5	6.3	.50	.....	.....	11.3	7.6	6.6	9.8	8.3	3.9
Strong acids																			
Sulphate (rSO_4)	26.7	33.8	46.3	.9	.8	2.0	5.03	34.0	35.3	19.6	45.34	11.5	15.1	32.5	20.7	43.4	37.0	30.7	40.9
Chloride (rCl)	2.3	.8	3.7	8.5	10.2	24.0	44.02	12.4	14.7	9.8	4.92	1.2	1.5	6.5	7.8	6.6	7.8	7.7	9.1
Weak acids																			
Carbonate (rCO_3)	3.9	2.6	.....	.....	7.6	2.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Bicarbonate($rHCO_3$)	17.1	12.8	.....	40.6	31.4	21.5	.97	3.6	.....	20.6	.79	37.3	33.4	11.4	12.5	.....	4.5	11.6	.....
Analysis as reported:																			
Sodium sulphate	491	927	17,430	.....	32	106	.....	11,680	1,524	9	.....	545	.....	.....	368	395	402	473	580
Sodium chloride	36	18	1,243	.....	.....	1,073	.....	3,485	781	18	.....	48	.....	.....	549	513	511	561	520
Sodium carbonate	53	55	.....	.....	237	106	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sodium bicarbonate	305	350	.....	.....	1,515	1,390	.....	219	.....	.....	.....	2,041	.....	.....	.....	.....	.....	.....	.....
Calcium sulphate	.....	.....	833	.....	.....	.....	.....	.....	631	34	.....	.....	.....	.....	2,060	1,895	1,885	1,421	1,920
Calcium carbonate and bicarbonate	.....	35	.....	.....	40	.....	.....	506	.....	36	.....	45	.....	.....	478	.....	429	1,157	.....
Magnesium sulphate	.....	.....	723	.....	.....	.....	.....	.....	84	14.5	.....	.....	.....	.....	.....	362	687	627	233
Magnesium carbonate and bicarbonate	.....	25	.....	.....	18	.....	.....	534	.....	.....	.....	.....	.....	.....	666	.....	.....	.....	.....
Iron and alumina	Nil	Nil	Nil	.....	Trace	Trace	.....	Nil	Trace	Trace	.....	Trace	.....	.....	Nil	Nil	Nil	Nil	Nil
Silica	18	26	Trace	.....	16	15	.....	52	8	6	.....	Trace	.....	.....	26	24	4	16	Trace
Hydrogen sulphide	Nil	.....	.....	.....	.....	.....	.....	.....	Nil	.....	.....	.....	.....	.....	.....	.....	20	Nil	.....
Bicarbonates calculated as $CaCO_3$	348	280	260	.....	1,186	.....	.....	900	620	48	.....	1,280	.....	.....	190	216	206	138	172

13. Midwest Oil Co. Crowe No. 2. From sand 1525–1680, hole starts in second Wall Creek. Water probably Sundance. Collected by J. A. Brady. Analyst, S. U.

14. Midwest Oil Co. Crowe No. 1. Oil and water in Tensleep. Sampled by E. G. Sinclair. Analyst, S. U.

15. Fargo Oil Co. No. 20. Oil and water in Tensleep. Sampled from lead line by E. M. P. Analyst, S. U.

16. Fargo Oil Co. No. 21. Oil and water in Tensleep. Sampled from lead line by E. M. P. Analyst, S. U.

17. Fargo Oil Co. No. 22. Oil and water in Tensleep. Sampled from lead line by E. M. P. Analyst, S. U.

18. Fargo Oil Co. No. 23. Oil and water in Tensleep. Sampled from tank after heating by E. M. P. Analyst, S. U.

19. Fargo Oil Co. No. 27. Oil and water in Tensleep. Sampled from tank after heating by E. M. P. Analyst, S. U.

* Amount of Na probably too low, which accounts for low bicarbonate also by the method of assuming bicarbonate. Cf. "bicarbonates calculated as $CaCO_3$" which is obtained directly by titration. The latter figure is thus a check on the Na and HCO_3 of the analyses.

a little oil and water. Its high concentration is due either to evaporation of a constant small supply of water by the escaping gas,[1] or else it is due to faulty shutoff of the Morrison water above (3) to which it bears great similarity. The latter is regarded as more probable.

By detailed comparison of the analyses we thus conclude that the Tensleep waters differ in important respects from any other waters in the field so far as analyses are available to make a comparison. The only remaining conjecture is whether some mixture of waters from above could produce the waters found in the wells.

In all the waters above the Tensleep the strong alkalies comprise one-fourth to one-third of the total solids, while one-tenth of the total solids in the Tensleep water is included in the strong alkalies. No conceivable mixture of waters above could yield this result, unless at the same time there was an increase in alkaline earths by solution of alkaline earth salts from the wall of the hole. If enough gypsum were dissolved out of the formations as water percolated downward, we would obtain a relative increase of calcium. This could hardly take place while the water was running down the hole below the water strings, which are landed at the top of the Chugwater. This conclusion is a mere matter of opinion, for the writer cannot cite any analyses showing what changes may take place as water runs down the hole. The close similarity of the Tensleep water from Notches (14) (except its lower concentration) to the other Tensleep waters is striking and is good collateral evidence.

Another question was whether the water in the oil sand could be entering the sand from a single hole then spreading to the other wells. Two of the five wells produce very little water, and one of these is located between two wells pumping considerable water, which argues against the point of invasion from a single well. None of the wells produce more water than can easily be pumped.

TEMPERATURE OF FLUIDS AS A GUIDE TO SOURCE

A chart of the temperatures of the fluid pumped from the wells was prepared. It showed that the well making most water pumped the warmest fluid, even though another well producing more fluid

[1] R. V. A. Mills and R. C. Wells, "The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," *U. S. Geol. Survey Bull. 693* (1919).

with very little water was cooler. This pointed toward the conclusion that it is probably bottom water and could be shut off by plugging back. It has become almost axiomatic in California that a rise in temperature of the fluid produced by a well indicates that it will soon go to water. Oil-field temperatures have often been supposed to be somewhat higher than normal underground temperatures.[1] Whether this is actually true or not is mooted, and if so its explanation is still more debatable. The most obvious explanation would be that the hydrocarbons react with constituents of the ground waters in exothermal reaction. This is not established yet, but the California experience is field evidence in its favor. The writer believes[2] that most oil accumulations are in locations where upward movement of waters and the accompanying oil has taken place, due to structure. This would increase the temperatures in those localities. Whether this be true or not, it is safe to conclude that if the temperature of the fluid in a well making oil and water is considerably higher than the temperature of oil in other wells not making water, then the water cannot be from above the oil.

SUMMARY

Water analyses are of great practical importance both in development and production of oil.

No great store of chemical knowledge is needed to use them if the problem is approached by correct methods.

Samples should be taken during development from water horizons uncontaminated by mixture of waters and before drilling too far ahead. It is desirable to have several analyses from each water horizon before assuming that the horizons are characterized by certain chemical differences.

Analyses should be calculated to reacting values of ions in percentage, as suggested by Stabler, or to reaction properties of the water, as suggested by Palmer.

The analyses should be plotted in some graphic form for com-

[1] G. Sherburne Rogers, "The Sunset Midway Oil Field, California," *U. S. Geol. Survey Prof. Paper 117*, Part II (1919), pp. 43–44.

[2] E. M. Parks, "Migration of Oil and Water—a Further Discussion," *Bull. Amer. Assoc. Pet. Geol.*, Vol. 8 (1924), pp. 697–715.

parison. Three methods for graphic study of water analyses are briefly described and illustrated and a fourth cited. (*a*) Rogers' method (Fig. 1) is serviceable when many analyses are to be compared, but it does not always distinguish different waters. (*b*) Tickell's method (Fig. 2) is very good to supplement Rogers' or to use alone. (*c*) Collins' graphs are simpler than Tickell's. (*d*) A new method (Fig. 3), proposed by the writer, is simple, employs equal areas for equal reacting values, and visualizes all the ratios deducible from the analysis and gives differently shaped figures for different waters. Any one of the last three graphs serves to distinguish waters which could fall close together on Rogers' chart but which are nevertheless different.

Some tentative conclusions of Rogers and others regarding the chemical relations of oil-field waters are reviewed in brief.

The whole history of a well or group of wells is generally needed to solve a particular water problem, and water analyses alone should not be relied on, although the most promising single line of evidence if sufficient analyses are available.

Analyses of various waters from Dakota, Morrison, Sundance, and Tensleep sands of South Casper Creek and Poison Spider domes and Notches dome, Wyoming, are tabulated and studied graphically with the following conclusions:

a) The Tensleep differs sufficiently from all waters above to be distinguished. It is lower in alkalies and higher in alkaline earths. It shows high secondary alkalinity. All Tensleep water analyses present the same characteristics, even including one from the Notches dome. The Tensleep waters are moderately concentrated.

b) The Dakota water is remarkable for the amount of soda ash in solution, is rather low in concentration, and is a primary alkaline water, being thus the antithesis of the Tensleep water.

c) The Morrison water is very concentrated, high in sodium plus potassium and in sulphate, and low in secondary salinity.

d) The waters of least questionable origin from the Sundance gas sands are less concentrated than the Tensleep water but more concentrated than the Dakota water, are high in chloride and low in sulphate, three of them containing very little sulphate. They are primary alkaline waters except two, one of which is from a lime at the base of the Sundance below the gas and differs markedly from the other Sundance waters, and a second, which is nearly on the line between secondary salinity and primary alkalinity. The Sundance waters present

in general the characters predicted by Rogers for waters associated with hydrocarbons except 9, which is from a lime below the gas and oil of the Sundance.[1] The writer is inclined to emphasize this fact and to predict that waters below oil and gas zones will generally not show alterations by reaction with hydrocarbons and that those above are more likely to show such alterations.

e) Two analyses, one from the drip on gas line (10) and the other from the pump (6), show that samples from the drip are of no use in studying water in the well.

f) The Tensleep waters do not present the characters we should expect in waters closely associated with oil and are more like surface waters. This is probably because the water horizon is below the oil and separated by some parting not noticeable in the logs, and the surface characters are due to artesian circulation downward from the outcrop, thus flushing out the connate waters.

[1] No. 13 is from the Notches where there is no oil or gas in the Sundance.

AIRPLANES FOR GEOLOGIC EXPLORATIONS IN INACCESSIBLE REGIONS[1] [2]

B. COLEMAN RENICK
United States Geological Survey, Washington, D.C.

ABSTRACT

Airplanes for carrying on geological investigations in difficultly accessible regions is recommended, and the practicability of this method of exploration is discussed. The problem of keeping a geologic party that has been transported by airplane also equipped and supplied by the same means of transportation and the utility of the airplane for reconnaissance by a geologist and for photographic purposes are treated. A considerable part of the paper is devoted to a description of the types of land and sea planes now in use by the United States Army Air Service and the Navy Bureau of Aeronautics that are serviceable for geological investigations in more or less remote regions. The amphibian in most cases will doubtless be the most serviceable and economical as well as the safest type of plane for an oil or mining company to use in such work. It is reasonable to predict that it will be a relatively short time before a two-motor amphibian plane will be perfected and such a plane will be extremely servicable for geological expeditions into remote regions.

INTRODUCTION

The science of aviation moves swiftly. A little over two decades ago (1903) the Wright Brothers, pioneer birdmen, took the first motor-driven plane into the air, stayed a few moments, and flew less than a mile. In the summer of 1924 the fliers of the Army Air Service "hopped off" at Seattle and encircled the earth. Much of the knowledge that has been gained of motors and planes in these past twenty-two years will be successfully employed for some time to come. On these fundamentals the science goes forward at an inconceivably rapid pace, discarding today the plans and designs that were current yesterday. The airplane has swung into the fields of

[1] Published by permission of the Director, U. S. Geological Survey, Washington, D.C.

[2] The photographs of the several planes that are here used as illustrations have been kindly furnished by the Air Service of the United States Army, and the Bureau of Aeronautics of the United States Navy. Acknowledgments are due to the following officers of the Army Air Service: Brigadier General J. C. Fechet and Lieutenant Lester Maitland, for kindly reviewing the manuscript; and Lieutenant C. P. McDarment, for cooperating by furnishing certain data. Thanks are also extended to a number of pilots of the Army Air Service with whom the author has had the pleasure of flying.

commerce and industry, and air transportation on schedule, of passengers, mail, and merchandise, is a reality. Within the last few years engineers and scientists other than aviators have adopted this medium of transportation in the furtherance of their work.

In spite of the fact that in this rapidly developing science, records of endurance, speed, altitude, and distance are being constantly shattered, a plane that is modern and standard today will be serviceable several years from now. The airplane may be very useful in several phases of geologic work. These include: (1) vertical aero-photography for the purpose of constructing either mosaics or base maps; (2) oblique aero-photography for compiling base maps and for assistance in establishing triangulation; (3) reconnaissance in difficultly accessible regions (supplemented by oblique photographs); (4) transportation of personnel and equipment for mapping geologic work in difficultly accessible regions and keeping the party thus transported supplied.

During the past five years the Army Air Service and the Navy Bureau of Aeronautics in the United States and the Royal Canadian Air Force in the Dominion have co-operated with several government bureaus in photographing areas for the purposes of assembling mosaics from aerial photographs and for compiling base and topographic maps. The preparation of maps by aerial surveys is, however, by no means confined to government projects, for there are in existence at the present time several corporations that are equipped with pilots, engineers, draftsmen, planes, cameras, etc., which are now actively engaged in aerial mapping, and much valuable work has been done by them in many types of engineering. During this period of development of aerial mapping, a number of papers have appeared that describe the several methods of assembling maps from aerial photographs, and a recent publication[1] contains a bibliography of the more important papers on this subject. There are different methods of preparing maps from aerial photographs depending upon several factors, such as (1) the type of camera that is used, (2) whether the photographs are vertical or inclined, (3) the ground control, (4) the scale of the map that is to be prepared, and other factors.

[1] "List of the More Important Recent Publications on Aerial Photographic Mapping and Surveying," *Fairchild Aerial Surveys Bull. 4*, 1925. (In press).

By means of the airplane and airplane photographs, the topography, certain types of physiography and land forms may be satisfactorily studied. Willis T. Lee has been very successful in investigating the physical features along the Atlantic Coastal plain by this method, and the results of his work are set forth in two recent publications,[1] both of which are illustrated by many excellent photographs. Other geologists[2] of the United States Geological Survey have had considerable success in mapping geology on mosaics assembled from aerial photographs.

It is recognized that there is a great field of work for the geologist in the application of aerial maps and mosaics compiled from aerophotographs to geological surveys, but it is not within the scope of this paper to consider these subjects. The theme of the present paper is a consideration of the feasibility of carrying on geologic exploration in difficultly accessible regions by airplane, a discussion of some of the more important factors involved in exploration of this type and a description of the types of planes that are suitable for such work. There is no doubt but that in many difficultly accessible regions it would be extremely helpful to the geologist to have the region photographed from the air and a mosaic or base map prepared before actual mapping of the geology is commenced, but in some cases the expense may make such an operation inadvisable.

FEASIBILITY AND CONSIDERATIONS INVOLVED

When we realize that the transcontinental United States air mail operates daily throughout the year with rarely more than a few minutes variation in schedule and that the scheduled passenger and freight air routes in Europe cover over 10,000 miles, there is left little room for doubt that planes operating from a suitable base of supplies may be relied upon as a means of transportation, and that it is entirely feasible to land a party by airplane several hundred miles from a base and keep it equipped and supplied by the same means. In South America, Africa, Asia, North America (mostly Canada and

[1] Willis T. Lee, "The Face of the Earth as Seen from the Air, *Amer. Geog. Soc. Spec. Pub. No. 4*, 1922; "Airplanes and Geography," *Geog. Rev.*, Vol. 10 (1920), pp. 310–25.

[2] M. R. Campbell and Edward Sampson, personal interviews.

Alaska), and perhaps in parts of Australia, there are considerable areas where geological investigations would be greatly facilitated by the employment of aircraft.

Considering the proposition from the point of view of an oil or mining company desiring to map an area with respect to possible petroleum or other mineral resources in the interior of one of the above-mentioned continents—a locality 500 miles from a base may be reached in less than a day, and when this short amount of time is compared with the many weeks necessary to cover the same distance by pack train or boat, the salary of the personnel and cost of maintenance being considered, there is little doubt but that an airplane expedition would be economical despite the original cost of the plane, or planes, for they may be utilized on many such expeditions.

The distance from a base of supplies to the field of operations is obviously an important consideration in discussing the types of planes adaptable for geological exploration. It is probably unlikely that it would generally be necessary for a plane to operate for a distance greater than 500 miles from a base or for a total distance of more than 1,000 miles, though to this rather general statement there are doubtless exceptions. Taking this as an arbitrary basis the several types of land and sea planes suitable for such work are here described. This discussion is confined almost entirely to planes that are being used by the United States Army and Navy, and foreign-made planes, in general, have not been considered; not because they are not suitable for such use, but because the author is not familiar with them, and specific data regarding the capabilities and recent developments of the many different makes and models are not at hand. The smallest plane that would be acceptable for this type of work must be capable of carrying sufficient gasoline and oil for the flight from the base of supplies to the area that is to be mapped, and return, plus a small reserve, some camp equipment and provisions, and two men besides the pilot. Additional men and supplies could be transported from day to day, and in many projects one plane in good condition would be sufficient, but it would be highly desirable to have two, and even more if the size of the expedition warranted. All of the planes described below may, with slight

alteration of the fixtures, be converted from a passenger- and freight-carrying plane to a photographic plane, and in some cases it may be desirable to use it for both purposes simultaneously.

It is understood that, in general, the smaller the amount of gasoline that it is necessary to transport, the greater the load in the form of camp equipment, rations, and instruments that may be transported. In figuring the load that a plane is capable of carrying, I have considered that the average airplane motor will consume between 20 and 25 gallons of gasoline and oil per hour, that gasoline weighs about 6 pounds per gallon and oil about 7 pounds per gallon, and that the average weight of a man is about 165 pounds. In every case, several hundred pounds below the maximum carrying capacity of the plane has been allowed as a safety factor.

Obviously, the greatest difficulty in using an airplane in remote, little-inhabited regions is the scarcity of landing fields. In unforested regions, relatively smooth stretches of country suitable for bringing a land plane to the ground are not altogether uncommon, and the probability of these areas being present in proximity to the area that is to be mapped geologically is not promising. Many of the areas in which an airplane might be used to best advantage are heavily timbered, and suitable landing places are generally wanting. A land plane equipped with wheels would not be satisfactory in such forested regions, but there are generally lakes and rivers in such regions in which a naval plane, equipped with pontoons, might land with perfect safety. But, if a naval plane were operating in such a region and should be so unfortunate as to have engine trouble some distance away from a body of water, and a forced landing were necessary, it would be incapable of effecting a safe one. There has recently been considerable advancement both in this country and abroad in the development of the helicopter and perhaps the time is not far distant when cross-country planes with helicopter characteristics capable of landing in relatively small areas will be a reality, and the question of large landing fields in forested regions will then not be such a critical one. This discussion, however, is concerned with the landing fields requisite for the types of land planes now in use, most of which take off and land at a speed greater than 50 miles an hour and therefore require a considerable area of fairly

smooth ground. In regard to landing facilities in heavily timbered country, especially in the tropics, a paper by Willis[1] is instructive. The advantages of a plane capable of operating on either land or sea are obvious, and a so-called "amphibian plane" that possesses these characteristics is referred to on pages 955–57.

There are necessarily many ramifications to the problem of geological exploration by airplane, depending upon the nature of the region that is to be visited and its proximity to centers of population. A base of supplies might be established by transporting the necessary equipment and supplies as close to the field of operations as possible by motor trucks, railroads, or steamboats, depending upon the mode that might be the most feasible. If, because of the lack of landing places, it would be impracticable to land a plane close by the area that is to be mapped, an airplane might be used to advantage by transporting the personnel and equipment as far as possible by air and from there proceeding on foot or by pack train and with the assistance of native carriers.

In an arid, or semi-arid country with some relief, as, for example, much of the Western United States, a geologist is able to obtain good reconnaissance data from an airplane, and oblique aerial photographs are useful in many place as an aid in visualizing the structure. But in a country similar to the Eastern United States, where there is considerable vegetation, as, for instance, the Piedmont Plateau and the Appalachian Mountain belts, most of the geologic structural relations, which are complex, are not evident from the air, though the topographic features are well displayed. In heavily vegetated country, such as obtains in much of the tropics, little regarding the geology is to be expected as a result of aerial reconnaissance supplemented by aerial photographs, but important data regarding the topography and drainage lines may be procured by such means.

LAND PLANES

The Douglas cruiser (Plate 13*A*), which is the plane that was used in the recent round-the-world flight, may easily be converted from a land to a sea plane by exchanging the wheels for pontoons.

[1] W. F. Willis, "A Survey for Aerodomes in Africa," *Geog. Jour.*, Vol. 60 (1920), pp. 459–63.

a

Official photograph, U S. Army Air Service

A DOUGLAS CRUISER

One of the round-the-world planes in flight. Here equipped with pontoons

b

Official photograph, U. S. Navy, Bureau of Aeronautics

THE DT 6

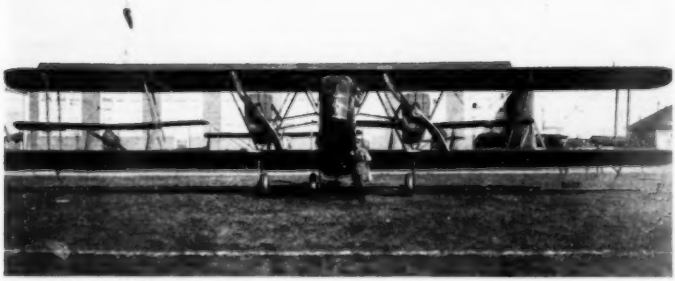
A naval plane that contains the largest air-cooled airplane engine that has been produced in this country. Here it is seen equipped with wheels instead of pontoons.

a

Official photograph, U. S. Army Air Service

THE T 2.—A FOKKER MONOPLANE

This is the plane that made the non-stop coast-to-coast flight in 1923



b

Official photograph, U. S. Army Air Service

THE MARTIN TRANSPORT

Note the size of this plane as compared with the two DH's and Sperry that are back of the Martin.

This plane is equipped with one Liberty motor and has an average cruising speed of about 80 miles an hour. If the present standard two-capacity seating arrangement is altered, the plane is capable of transporting a pilot and two men, sufficient oil and gas for twelve hours flying, and a load of at least 1,500 pounds.

The Army T-2 model, which is a Fokker monoplane (Plate 14*A*), is the type in which Lieutenants Macready[1] and Kelley made their non-stop, coast-to-coast flight in 1923, and it also is equipped with one Liberty motor. This plane has an average cruising speed of about 70 miles an hour, and by removing certain military equipment it is easily capable of carrying a pilot and two persons, sufficient uel for 1,000 miles of flying, and a load of 1,800 pounds.

The Martin transport (Plate 14*B*), which is a Martin bomber without the military fixtures, is equipped with two Liberty motors and has an average cruising speed of 90 miles an hour. It is easily capable of transporting three or four men, sufficient gasoline for 800 miles of flying, and some equipment. The presence of two motors affords a safety factor against forced landings due to possible trouble in one or the other of the motors, but this is offset to some extent by the relatively large gasoline consumption of the two engines (approximately 45 gallons an hour), and the relatively large space necessary for landing the plane. Plate 11*B* shows the size of the Martin transport as compared with the two DeHavilands (DH's) and a Sperry Messenger.

Any of the above-mentioned land planes are satisfactory for geological exploration in regions where there are adequate landing facilities. The smaller types of army planes such as the DH, DWH, Voight, and Sperry, etc., which have a relatively small cruising radius and small capacity, are hardly adaptable to any extensive geological expedition.

The latest Douglas and Curtiss observation planes are reported to have a cruising radius of approximately 700 miles, and planes of this type would be satisfactory for photographic and reconnaissance work in many regions. As these are small, two-place planes, they would probably not be suitable for transporting personnel and

[1] Lieutenant J. A. Macready, "The Non-Stop Flight across America," *Nat. Geog.*, Vol. 46 (1924), pp. 1–83.

equipment, and if a company utilized a plane of this type for reconnaissance and photographic purposes, it would be necessary to have a larger plane for maintaining a geologic party.

In any discussion relating to airplanes one can hardly refrain from referring to the Air Service Barling Bomber which is doubtless the largest heavier-than-air plane that has yet been built in the United States. Its power plant consists of 6 liberty motors which together develop over 2,400 H.P. and it has a speed of about 95 miles an hour. The Barling empty weighs 27,100 pounds and with its military load including a crew of ten men, fuel, oil, bombs, etc., it weighs over 42,000 pounds. This plane is obviously too heavy and large for geological expeditions and it lacks the maneuvering qualities of smaller planes. Also it would be uneconomical because of the large initial cost and the expense of operation.

SEA PLANES

Turning now to a consideration of the principal types of naval planes that are suitable for work in regions where there are places for water landings, the SC 1 (Plate 15*A*), though a naval plane, may be converted into a land plane by exchanging its pontoons for wheels. This is a three-place plane and is equipped with a Wright T-3 engine (575 H.P.). It is used by the Navy as a scout, bomber, and torpedo plane. It has an average cruising speed of about 90 miles an hour, and a normal range of about 1,500 miles. The gasoline tanks necessary for this cruising radius could be decreased in size, and the ship could transport an amount of freight equal to the decrease in the weight of gasoline.

The PN-9 (Plate 15*B*), which is one of the latest developments of the Navy Department, is a long-distance, patrol plane and is equipped with two Packard engines of over 500 H.P. each. On May 1 and 2, 1925, this plane established the world's record for sustained flying. With a crew of four men and a total weight of nearly ten tons, this plane remained in the air for 28 hours and 38 minutes at an average speed of 80 miles an hour and covered approximately 2,300 miles. The maximum speed of this plane is reported to be about 117 miles an hour. The PN-9 in this test, therefore, consumed about 45 gallons of gasoline per hour, and it would thus require approxi-

a

Official photograph, U. S. Navy, Bureau of Aeronautics

THE SC-1

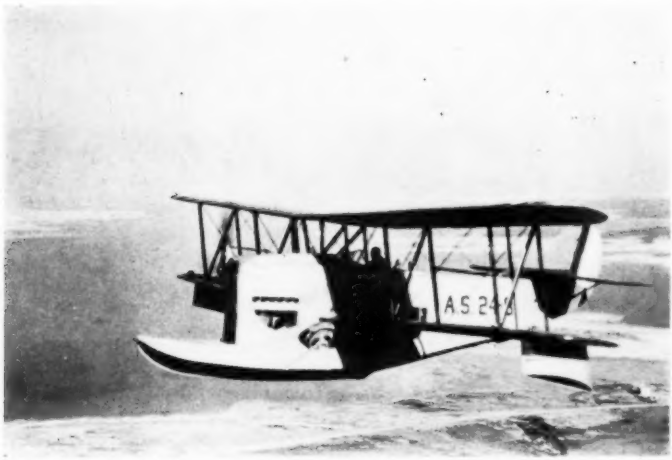
A three-place naval plane

b

Official photograph, U. S. Navy, Bureau of Aeronautics

THE PN-9

This plane on May 1 and 2, 1925, remained continuously in the air for over 28½ hours and covered approximately 2,300 miles, which is a new world-record for continuous flying.



a

Official photograph, U. S. Army Air Service

THE LOENING AMPHIBIAN IN FLIGHT

The wheels that are used for landing on the ground are here seen folded back into the hull. With the landing gear in this position the plane lands in water.

b

Official photograph, U. S. Army Air Service

THE LOENING AMPHIBIAN

The Liberty motor used in this plane is inverted

mately 560 gallons of gasoline in order to cover 1,000 miles. It is therefore easily capable of transporting sufficient fuel for 1,000 miles of flying, four or more men, and six tons of freight. This plane possesses most of the requisites for geological exploration, but would probably be expensive to own and operate. The Navy Department expects to use this plane for the non-stop flight from the Pacific Coast to Honolulu which is scheduled to take place later in the summer.

The Boeing Patrol is another boat-type, metal seaplane which is now under construction and is similar in many respects to the PN-9, but its two Packard motors are arranged in tandem. It is also expected to be capable of making a non-stop flight of approximately 2,500 miles.

Another very recent development of the Navy Department is the DT-6 (Plate 11*B*), a convertible plane, which is unique in that it contains the largest air-cooled airplane engine that has been produced in this country. It has an average speed of over 100 miles an hour. Although details as to the capacity load of this plane are not at hand, it is significant that there is a considerable saving in weight owing to the elimination of the water-cooled system. It is claimed that the Liberty motor involves a weight of 3.2 pounds per H.P., while the new air-cooled Wright motor that is used in this plane involves a weight of but 2 pounds per H..P.

The Naval U.O.-1 plane, which is a shipboard spotter, is carried by battleships and cruisers, is launched by a catapult, and is interesting, but because of its short endurance (about 400 miles) is not adaptable for most geological explorations.

AMPHIBIAN PLANES

Although several of the above-mentioned land and sea planes may be converted by having their wheels exchanged for pontoons, or vice versa, none possess amphibian characteristics, i.e., are capable of landing on either land or sea without changing their landing gear, and it is apparent that a plane possessing these characteristics would not only be the safest but also the most serviceable and economical type for an oil or mining company to own inasmuch as it could be operated in any region. Aeronautical engineers, for at least

several years, have appreciated the desirability of developing an amphibian plane comparable with the best types of land and sea planes. In this connection, it is interesting to note that the Topographical Survey of Canada, in co-operation with the Royal Canadian Air Force in 1924 in making oblique photographs of the Reindeer Lake and Churchill River districts, Saskatchewan and Manitoba,[1] for mapping purposes, used a Vickers Viking amphibian type plane equipped with one Eagle 9 Rolls-Royce 360-H.P. engine.

On this expedition the wheels and attachments were removed from the Vickers amphibian in order to decrease the load, as there are many lakes and rivers suitable for water landing in this part of Canada. Four persons were engaged in this project: (1) a navigator, a land surveyor from the Topographical Survey; (2) a photographer; (3) a pilot, and (4) a mechanic. Motor fuel and supplies were sent to certain stations in advance of the party. Three hundred and twenty-five miles was the longest flight that was made, and most of the flights were not over 250 miles, and at the end of each flight, gasoline and oil and other supplies were available. In order to carry sufficient fuel, together with the crew of four men and the necessary equipment, the plane was taxed to its utmost and sometimes experienced difficulty in leaving the water. If a larger two-motor amphibian plane with greater carrying capacity were in existence, it would be most suitable for work of this type.

The Loening Amphibian (Plate 16), an American plane designed by Grover Loening, is probably the most modern development along this line. Because of its many splendid qualities and because an amphibian plane is the type most adaptable to geological exploration, it is described in some detail below.

This plane is equipped with a Liberty motor that has been inverted, by which arrangement the propeller thrust is so high at the top of the body that the entire fuselage is built in the form of a compact-unit hull. The hull is covered with duralumin and the interior construction of the wings is of the same material. The first Loening amphibian plane was delivered to the Air Service on Janu-

[1] *Department of National Defense Report on Civil Aviation for 1924*, Appendix D (1925), pp. 92–103.

ary 18, 1925, and was tested by Lieutenant W. H. Brookley.[1] He states that it performs splendidly when landing or taking off on either land or water. For sea landings the wheels are folded into the hull by either a hand crank or an electric motor. Plate 14*B* is a view of the plane resting on the wheels, and Plate 14*A* is a view of the plane in flight with the wheels folded into the body. It is in this latter position that the amphibian is a sea plane and capable of landing in water.

The Loening amphibian with retractable skees, instead of wheels, is the plane that is now being used by the Navy Department in the present North Pole expedition under the command of Captain Donald B. McMillan. This amphibian is a two-place plane, but the observer has two seats, one in the gun ring and another below for photographic work which is entirely protected from the wind. In the bottom of the hull there are removable port holes for the camera. The maximum speed of this plane is approximately 120 miles an hour. It is about the same size as the average high-speed, pursuit plane, weighs about 3,390 pounds empty, and has a carrying capacity of about 1,600 pounds. If the plane contained a load of two men and a pilot and sufficient gasoline and oil for traveling 1,000 miles, it would be unable to carry anything else.

At the present time, however, there is being developed a three-place Loening amphibian with a Packard motor, and it seems safe to predict that it will be a relatively short time before a larger, two-motor amphibian plane with much greater carrying capacity will be a reality. A bi-motor amphibian plane would be most satisfactory for geological exploration, since it would be adaptable to either land or water landings and would possess an adequate carrying capacity for transporting and maintaining a geologic party in the field. It is recognized, however, that the present Loening amphibian is probably suitable for shorter expeditions, and by repeated trips to and from the base of supplies one of these planes could probably keep a small field-party several hundred miles from the supply base equipped and supplied.

[1] "The New Loening Amphibian," *Air Service News Letter*, Vol. 9 (April 20, 1925), No. 7.

THE BARBERS HILL OIL FIELD, CHAMBERS COUNTY, TEXAS

GEORGE M. BEVIER[1]
Houston, Texas

ABSTRACT

Barbers Hill is a moundlike elevation in the extreme northwestern portion of Chambers County, Texas, 26 miles northeast of Houston. It is oval in shape, covers an area of 1,718 acres, and rises 45 feet above the surrounding prairie. This elevation is the result of an intrusive salt plug which has raised the surface above its normal position.

The salt plug is composed of almost pure rock salt and is capped by deposits of gypsum anhydrite and limestone. Formations surrounding the salt plug are inclined at steep angles dipping away from the salt plug.

Numerous indications of geologic disturbance are present on and about the dome. The most prominent of these are mineralized water-and-gas seepage in shallow water wells, paraffin dirt, and gas seepage on the surface.

Prior to 1924, 120 wells were drilled, of which 26 produced oil and 91 were failures. The total production for this period is 784,520 barrels, all of which was obtained from an area of 100 acres on the southwestern side of the dome. The average production of producing wells has been 30,174 barrels, and the average depth 2,251 feet. The oil has an asphaltic base with gravities ranging from 17° to 39°7 Baumé; the oil produced from cap rock averages about 20° Baumé. Production around the periphery of the dome is obtained from sands and limestones of the Fleming formation.

INTRODUCTION

Barbers Hill is a moundlike elevation in the extreme northwestern portion of Chambers County, Texas. It is 26 miles northeast of Houston, 11 miles north of Goose Creek, and 21 miles southeast of the Humble oil field. The village of Mont Belview is situated on top of the mound. The most convenient method of approach is by automobile from Houston. It is also accessible via the Dayton and Goose Creek Railroad, which connects with the main line of the Southern Pacific at Dayton.

HISTORY OF DEVELOPMENT

In 1889, Mr. E. W. Barber encountered inflammable gas while digging a 65-foot water well near his home. The well is located near the top of the mound and produced small quantities of gas for many years.

Following the discovery of oil at Spindletop in January, 1901, Barbers Hill was one of the first prospects to receive the attention of early operators. Its

[1] Geologist, Atlantic Oil and Producing Company, Houston, Tex.

prominent elevation, with inflammable gas and sulphurated water in shallow wells near the top, strongly suggested the presence of an underlying salt dome.

During the month of February, 1902, Dr. George Collier recorded the first oil-and-gas leases taken at Barbers Hill; these leases covered the Old River, Lawrence, and Barber tracts. A portion of these holdings were transferred to Patillo Higgins under a drilling agreement, and four months later the first well was started on the Old River tract, well up on the northwestern slope of the hill. After reaching a depth of 934 feet, the well was junked in hard cap rock. A showing of heavy oil is reported in sand at 800 feet immediately above the cap rock. A total of five wells were drilled by Mr. Higgins, all of which encountered cap rock showing a little oil but failed to obtain sufficient quantities to make commercial production. In 1903, Mr. J. M. Guffey entered the field jointly with the Higgins Oil and Fuel Company and drilled five wells. The first two locations were on the Mary Ellen property (now DeWitt Barber), on the southern slope of the hill. A small amount of heavy, viscous oil was obtained at 805 feet from sands immediately above the cap rock.

Fourteen wells were drilled during the next four years without obtaining production. All of these wells were shallow, the majority being located on top of the dome. Operators became discouraged, owing to the low price of crude oil from 1906 to 1916, and very little activity was manifest at Barbers Hill. However, the success attained by deeper drilling along the periphery of other domes finally led Mr. Guffey to make a location on the Fitzgerald tract at the base of the northern slope of the hill. A depth of 2,520 feet was reached after passing through a series of unconsolidated sands, clays, and gravel containing no oil. In 1916 the Gulf Production Company, successors to the Guffey interests, jointly with the Humble Oil & Refining Company, drilled four wells, all of which are located on the Chambers County Agricultural Association's land near the southern slope of the hill. The fourth well obtained the first production at Barbers Hill, estimated at 40 barrels per day, from a sandy formation at 1,571 feet. The oil is reported as dark brown in color, heavy and viscous. The well was abandoned when salt water appeared after the production of a small quantity of oil. In 1918, Mr. Sam Hindman organized the United Petroleum Company and completed Fisher No. 1, on September 14, 1918. The initial production was 70 barrels per day of oil of 23° Baumé gravity, and the well continued to produce for a period of fifteen months. This was the first successful completion in sixteen years of drilling.

The success of this well, together with an increase in the price of crude oil, was responsible for many new locations. Several wells were completed later in the year, and by January 1, 1919, production had increased to 600 barrels per day. The decline was very rapid, however, and by April 15 there was insufficient oil to supply fuel for drilling operations. However, the completion of a 650-barrel well by Benkenstein on the Collier tract, together with other producers by the Texas Company and United Petroleum Company, increased the daily

average production to 1,000 barrels during the months of August and November, 1919. In April, 1920, the United Petroleum Company completed Richardson No. 4 as a 700-barrel well at 1,960 feet. The oil had a gravity of 21° Baumé and was the best producer so far obtained.

The year 1921 was a period of relative inactivity, with the exception of the United Petroleum Company's No. 1 E. E. Barrow, which was completed during the latter part of December at a depth of 3,560 feet for 800–1,500 barrels per day of oil of 35° Baumé gravity. This was the first well to secure oil from edge sands around the dome and was by far the best producer of the field.

An active drilling campaign followed in an effort to develop the newly discovered productive deep sands, the United Petroleum Company, Humble Oil and Refining Company, and Mills Bennett being particularly active in this work. By October, 1922, the monthly production had increased to 53,800 barrels. This increase is largely due to the completion of Japhet No. 1 in October, 1922, by Mr. Bennett. It is the best well so far obtained at Barbers Hill and has remained a consistent producer to the present time. Initial production was 1,800 barrels per day, with a temperature of 78° F. The oil is of 34°.5 Baumé gravity and is similar to that obtained from the United Petroleum Company's No. 1 E. E. Barrow.

In 1923 the Texas Company drilled three wells on the northeastern portion of the dome without obtaining production. Sheffield No. 1 and No. 2 were abandoned in broken cap rock, showing a little heavy oil. No. 1 Scott was abandoned at 4,635 feet without obtaining a showing of importance. Outside of the Texas Company's operations, very little new work was attempted, and by January 1, 1924, there were but 5 producing wells, having a combined daily average of 550 barrels. At the present time (August, 1924), there are 3 producing wells in the field, having a combined daily production of 150 barrels per day.

A total of 120 wells, including 10 wells which were primarily sulphur tests, have been drilled at Barbers Hill. Of these 26, or 21.7 per cent, were productive, and 94 non-productive. A total of 784,520 barrels of oil has been produced throughout a period of six years. The average production per well is 30,174 barrels, and the average depth is 2,251 feet. It is evident that the revenue from oil produced is little more than sufficient to pay for the drilling and operating costs. All of this oil has been obtained from an area of 100 acres on the southwestern portion of the dome and amounts to an average production of 7,845 barrels per acre.

PHYSIOGRAPHY

Barbers Hill lies within the Gulf Coastal plain, 33 miles inland from the Gulf of Mexico. It is surrounded by comparatively flat country, sloping gently toward the gulf at an average rate of about 1 foot per mile. The topographic expression of the salt dome is a hill somewhat oval in shape and covering an area of 1,718 acres (Fig. 1).

TABLE I

Development at Barbers Hill

Operator	Tract	Well No.	Date	In. Prod.	Depth in Feet	Remarks
Patillo Higgins	Old River	1	1902	Dry	934	Junked—cap rock, 800–934 feet
Patillo Higgins	Winfree, M. C.	1	1902	Dry	560	Aban. in cap rock
Patillo Higgins	Barber, E. W.	1	1903	Dry	1,176	Aban. in cap rock
Patillo Higgins	Williams, A.	1	1903	Dry	465	Aban. in salt
Patillo Higgins	Higgins, A.	1	1904	Dry	1,052	Aban. in cap rock
G. M. Guffey	Ellen, Mary	1	1904	Dry	980	Aban. in cap rock
G. M. Guffey	Ellen, Mary	2	1904	Dry	805	Cap rock, 800–805 feet
G. M. Guffey	C. C. Agric. Ass'n	1	1904	Dry	1,805	Aban. in gumbo
Sun Co	Williams, A.	1	1904	Dry	1,802	Aban. in sand and salt
J. M. Guffey	Fisher, E.	1	1905	Dry	974	Aban. in cap rock
J. M. Guffey	Wilburn, Z. T.	1	1905	Dry	1,030	Aban. in rock
J. M. Guffey	Smith, J. H.	1	1905	Dry	1,457	Salt, 1,388–1,457 feet
Higgins Oil & Fuel Co.	Higgins (Fee)	1	1905	Dry	1,104	Aban. in cap rock
Higgins Oil & Fuel Co.	C. C. Agric. Ass'n	1	1905	Dry	1,490	Aban. in salt
J. M. Guffey	Fisher, E.	2	1906	Dry	1,200	Aban. in cap rock
J. M. Guffey	Wilburn, B. F.	1	1907	Dry	1,100	Aban. in gypsum
Jos. Reviere & Co.	Hamilton, J.	1	1908	Dry	1,206	Cap rock and gypsum, 863–1,206 feet
Home Oil Co.	C. C. Agric. Ass'n	1	1910	Dry	1,250	
Home Oil Co.	Fisher, A. M.	1	1910	Dry	2,100	Tested salt water
J. M. Guffey	Fitzgerald	1	1911	Dry	2,520	Aban. in gumbo
Community Oil Co.	Monon Trust Co.	1	1912	Dry	1,930	Strong sulphur water
Gulf Humble	C. C. Agric. Ass'n	1	1916	Dry	2,283	Show of oil at 2,200 feet
Gulf Humble	C. C. Agric. Ass'n	2	1916	Dry	3,523	No cap rock
Gulf Humble	C. C. Agric. Ass'n	3	1916	Dry	1,200	
Gulf Humble	C. C. Agric. Ass'n	4	1916	40	1,571	Small production
Prairie Oil Co.	Wilburn	1	1916	Dry	2,385	Aban. in hard rock
Anahuac Oil Co	Hamilton, J.	1	1917	Dry	410	
Hindman *et al.*	C. C. Agric. Ass'n	1	1917	Dry	1,380	Aban. in rock and gypsum
Benkenstein-W. P. Co.	Richardson	1	1918	65	1,600	21 gravity oil
United Petroleum Co.	Fisher, E.	1	1918	70	2,142	23 gravity oil
United Petroleum Co.	Fisher, E.	2	1918	300	1,065	18 gravity oil
R. L. Autry	Richardson	1	1919	200	1,491	19 gravity oil
Benkenstein Synd.	C. C. Agric. Ass'n	1	1919	270	1,860	18 gravity oil
Benkenstein Synd.	C. C. Agric. Ass'n	2	1919	Dry	1,870	Junked
Benkenstein Synd.	Collier	1	1919	650	1,847	18 gravity oil
Benkenstein Synd.	Old River	1	1919	Dry	1,680	Tested salt water
Benkenstein Synd.	Old River	2	1919	Dry	2,100	Tested salt water
Kavanaugh Pet. Co.	C. C. Agric. Ass'n	1	1919	Dry	2,165	No cap rock
Kavanaugh Pet. Co.	Fisher, E.	1	1919	Dry	1,340	Aban. in gypsum
Kavanaugh Pet. Co.	Fisher, E.	2	1919	Dry	1,960	Tested salt water
Hugh McCollum	Wilburn, B. F.	1	1919	Dry	1,300	Aban. in gypsum
Texas Co.	Fisher, Ben	1	1919	Dry	1,908	Tested salt water
Texas Co.	Fisher, Ben	1-A	1919	Dry	1,385	Aban. in gypsum
Texas Co.	Fisher, Ben	2	1919	200	1,918	21 gravity oil
Texas Co.	Fisher, Ben	3	1919	Dry	1,905	Tested salt water
United Pet. Co.	Fisher, E.	3	1919	Dry	1,910	Aban. in salt
United Pet. Co.	Richardson	2	1919	50	1,980	21 gravity oil
United Pet. Co.	Richardson	3	1919	Dry	2,385	Aban. in gypsum
DeWitt Barber	Ellen, M. (Gulf)	1	1920	Dry	1,032	Aban. in cap rock
DeWitt Barber	Ellen, M. (Gulf)	2	1920	50	820	17 gravity oil
DeWitt Barber	Ellen, M. (Gulf)	3	1920	20	810	17 gravity oil
DeWitt Barber	Ellen, M. (Gulf)	4	1920	25	845	Flooded by salt water
DeWitt Barber	Ellen, M. (Gulf)	5	1920	15	815	17 Gravity oil
Gambler Oil Co.	Barber, O.	1	1920	Dry	1,200	
Gulf Coast–Crown	Barber, E. W.	1	1920	Dry	3,721	Aban. in gumbo
Keeble (Trustee)	Fisher, Ben.	1	1920	Dry	350	Aban. in cap rock
Hugh McCollum	Wilburn	2	1920	Dry	1,600	No data
Old River Oil Co.	Richardson	1	1920	Dry	1,800	Little heavy oil
Old River Oil Co.	Richardson	2	1920	400	2,230	27 gravity oil
Spurrier Dev. Co.	Barber, O.	1	1920	Dry	1,231	Aban. in rock
Spurrier Dev. Co.	Wilburn, B. F.	1	1920	Dry	883	Aban. in gypsum
Spurrier Dev. Co.	Wilburn, B. F.	2	1920	Dry		
Texas Co.	Barrow, E. E.	1	1920	Dry	3,324	Junked—blowout at 3,200 feet
Texas Co.	Barrow, E. E.	1-A	1920	Dry	3,460	
Texas Co.	Barrow, F.	1	1920	Dry	2,782	Junked
Texas Co.	Barrow, F.	2	1920	Dry	678	Junked
Texas Co.	Fisher, Ben	3-A	1920	Dry	1,332	

TABLE I—*Continued*

Operator	Tract	Well No.	Date	In. Prod.	Depth in Feet	Remarks
Tex. Co.	Old River	1	1920	Dry	3,941	Aban. in gumbo
United Pet. Co.	Fisher (10 acres)	1	1920	Dry	2,653	Tested salt water
United Pet. Co.	Richardson	4	1920	700	1,960	21 gravity oil
United Pet. Co.	Richardson	5	1920	Dry	1,750	Aban. in salt
Gulf Coast—crown	Fisher, E.	1	1921	Dry	2,500	Salt, 1813–2,500 feet
Gulf Coast—crown	Fisher, E.	2	1921	Dry	2,265	Junked in hard rock
United Pet. Co.	Barrow, E. E.	1	1921	800	3,560	34 gravity oil
United Pet. Co.	Richardson	6	1921	Dry	2,070	Aban. in cap rock
Mills Bennett	C. C. Agric. Ass'n	1	1922	Dry	4,147	Tested salt water
Mills Bennett	C. C. Agric. Ass'n	2	1922	Dry	2,800	Aban. in salt
Mills Bennett	Japet	1	1922	1,800	3,236	34 gravity oil; tem., 78° F.
Mills Bennett	Japet	2	1922	1,700	3,760	
Mills Bennett	Japet	3	1922	800	3,503	27 gravity oil; tem., 80° F.
Dunnman Oil Co.	Fisher, Z.	1	1922	Dry	2,625	Aban. in salt
Hindman *et al.*	Japet	1	1922	Dry	2,858	Junked
Kirby Petroleum Co.	Richardson	1-A	1922	Dry	2,405	
Kirby Petroleum Co.	Richardson	1-B	1922	Dry	2,645	Junked
Kirby Petroleum Co.	Winfree	1	1922	Dry	4,074	Aban. in sandy shale
Texas Co.–W. P. Co.	Barrow, F.	1	1922	Dry	4,000	Tested salt water
United Pet. Co.	Richardson	7	1922	Dry	3,030	Aban. in cap rock
United Pet. Co.	Richardson	8	1922	400	2,238	
Mills Bennett	Barrow, E. E.	1	1923	Dry	3,488	Tested salt water
Mills Bennett	Barrow, E. E.	2	1923	1,000	3,817	39.7 gravity oil
Mills Bennett	Barrow, E. E.	3	1923	Dry	3,460	Tested salt water
Mills Bennett	Japet	4	1923	Dry	2,988	Tested salt water
Mills Bennett	Japet	5	1923	2,000	2,695	31 gravity oil
Coastal Oil Fields, Inc.	Barrow, F.	1	1923	Dry	60	
Coastal Oil Fields, Inc.	C. C. Agric. Ass'n	1	1923	Dry	1,700	
Coastal Oil Fields, Inc.	Fisher (fee)	1	1923	Dry	2,220	
Coastal Oil Fields, Inc.	Fisher, E.	1	1923	Dry	2,715	
Coastal Oil Fields, Inc.	Richardson	1	1923	300	2,225	29 gravity oil
Coastal Oil Fields, Inc.	Richardson	2	1923	Dry	2,385	Tested salt water
Hindman *et al.*	Collier	1	1923	Dry	1,398	Aban. in anhydrite
Hindman *et al.*	Collier	2	1923	Dry	951	Aban. in cap rock
Hindman *et al.*	Fisher, E. H.	1	1923	Dry	1,302	Aban. in cap rock
Hindman *et al.*	Shearer	1	1923	Dry	907	Cap rock and gypsum, 728–907 feet
Hindman *et al.*	Smith	1	1923	Dry	889	Cap rock and gypsum, 451–889 feet
Hindman *et al.*	Wilburn	1	1923	Dry	1,130	Aban. in cap rock
Hindman *et al.*	Wilburn	2	1923	Dry	1,280	Aban. in cap rock
Humble Oil & Ref. Co.	Blaffer	1	1923	850	3,115	33.6 gravity oil
Humble Oil & Ref. Co.	Blaffer	2	1923	1,000	3,511	
Humble Oil & Ref. Co.	Blaffer	3	1923	Dry	2,914	Tested salt water
Humble Oil & Ref Co.	Meyers	1	1923	85	3,606	33 gravity oil; tem., 79° F.
Republic Prod. Co.	Fisher, E.	1	1923	Dry	3,095	Tested salt water
Texas Co.	Scott	1	1923	Dry	4,635	Aban. in hard shale
Texas Co.	Sheffield	1	1923	Dry	1,128	Aban. in cap rock
Texas Co.	Sheffield	1	1923	Dry	2,237	Aban. in hard sand
Union Sulphur Co.	DeWitt Barber	1	1923	Dry	1,400	Top of cap 930 feet; aban. in salt
Union Sulphur Co.	Winfree, E.	1	1923	Dry	1,410	Top of cap 1,275 feet; aban. in salt
Union Sulphur Co.	Winfree, M. C.	1	1923	Dry	682	Top of cap 495 feet; aban. in salt
Union Sulphur Co.	Winfree, O. K.	1	1923	Dry	1,192	Top of cap 950 feet
Union Sulphur Co.	Winfree, O. K.	2	1923	Dry	552	Aban. in cap rock

It rises to a maximum height of 83 feet and extends 45 feet above the surrounding prairie. The major axis is 12,000 feet long, extending N. 43° W., and the minor axis is 9,250 feet long. Erosion has been active, and the effect of surface drainage is clearly demonstrated in a number of gullies which extend in all directions away from the higher portions of the dome. Several erosional undulations

have been formed which are entirely separate and distinct from, and have no bearing upon, the position of subsurface structure. There is, however, a general relationship between the shape and position of the mound as compared with that of the underlying

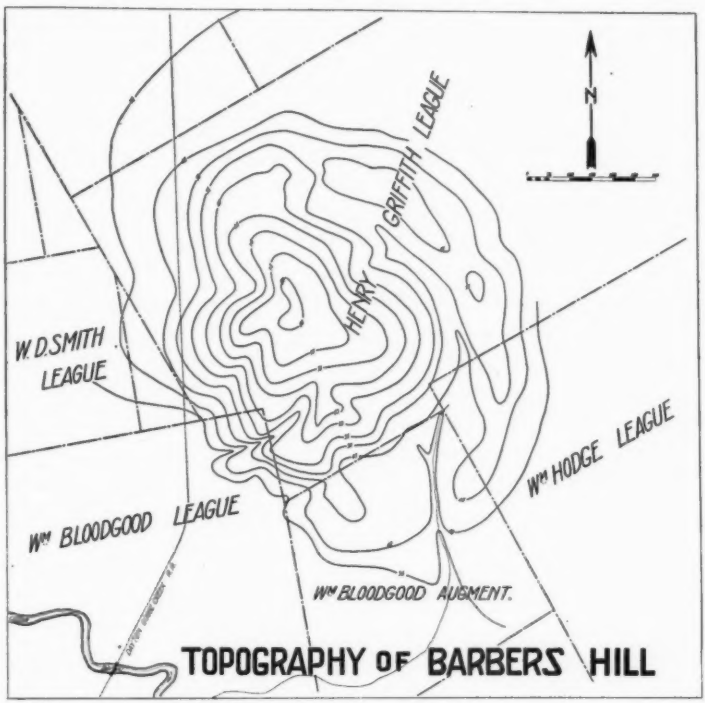


FIG. 1.—Topographic map of Barbers Hill

dome. The highest portion of the hill lies only 1,250 feet northwest of the center of the dome and from the highest known structural displacement. The 3,500-foot contour on the cap rock corresponds closely with the outline of the base of the hill.

GEOLOGY

General description.—The surface at Barbers Hill presents very few exposures, and our knowledge of structural conditions must be

gained essentially from a study of well logs, core samples, and drill cuttings. Cuts along the side of roadways near the top of the hill show 3 or 4 feet of mottled yellow clay, containing irregular patches and lenses of sandy clay, sand, and small calcareous concretions. The material apparently lies in a horizontal position but does not display bedding plains which can be used to define the attitude of the bed. Its texture and other physical characteristics are typical of the Beaumont clay.

A study of subsurface conditions shows the presence of an intrusive salt core capped by deposits of gypsum, anhydrite, and limestone. In the course of its development and growth, adjacent formations have been tilted or inclined at high angles, sloping in all directions away from the dome.

The upper extremity of the salt core is oval in outline, the top being essentially flat with slightly rounded edges sloping off at an angle of about 73° to an unknown depth. The southwestern edge, in the vicinity of the productive area, is faulted and irregular, showing an average dip of 59°. Core samples indicate that the salt plug is composed of almost pure rock salt, containing waves and bands of darker material, indicating flowage. Salt has been encountered in 10 wells; the Gulf Coast-Crown No. 1 Fisher entered rock salt at 1,813 feet and was abandoned at 2,500 feet still in salt. This is the greatest thickness of salt penetrated at Barbers Hill.

Cap rock.—"Cap rock" is a term generally applied to mineralized deposits adjacent to and above the salt plug. At Barbers Hill these deposits are largely composed of anhydrite, gypsum, and limestone, varying in thickness from 850 feet in the central portion to a few feet at the outer edges of the dome. They are extremely irregular and occur rather as lenses, pockets, and concretions, no two sections being alike. There is, however, a general arrangement of anhydrite below, limestone at the top, with gypsum between the two. The cap rock is generally porous and cavernous, containing variable amounts of sulphur, pyrite, and calcite deposited in crystal form throughout the porous spaces. Some of the crystals have rounded edges, indicating solution by circulating underground waters.

The upper portion of the cap rock is composed of very hard

limestone. Inclusions of gypsum and anhydrite have been noted together with an occasional thin parting of gumbo.

The cap rock rises to within 350 feet of the surface, as shown by the well known as Keeble Trustee, Ben Fisher No. 1. This well is 2,250 feet south of the highest portion of the dome.

Structure of surrounding sediments.—Contour lines as shown on Figure 2 indicate the top of the cap rock below the surface. These lines express the shape of the dome rather than the amount of structural displacement.

The surrounding sediments are inclined at steep angles, sloping in all directions away from the salt plug. Dips of 45°–50° are common within the producing area on the southwestern portion of the dome, and core samples locally indicate dips of 80° or more from points adjacent to or near the top of the cap rock. Other points to the north, northeast, and southeast of the dome show dips of 65°–70°. The field is characterized by steep dips, and the surrounding formations have been sharply upturned or broken at the point of contact with the salt plug, although they are not elevated to much above their normal position around the periphery of the dome.

Faulting.—Circumferential step faults, the downthrow side being directionally away from the dome, are proved, and radial faulting has been noted on the southwestern side between the United Petroleum Company's No. 4 Richardson and the Gulf Coast-Crown No. 1 Fisher. The presence of faulting can be established at Barbers Hill, but, owing to the extremely complicated structural conditions in which decided changes occur within narrow limits, it is difficult to define a particular fault or zone of faulting with accuracy. Crushed and shattered zones are present usually at the point of contact between the salt plug and surrounding sediments, indicating that considerable movement has taken place under heavy pressure. Faulting at Barbers Hill is the result of displacement, induced by an upthrust from below.

Stratigraphy.—The lateral beds surrounding the dome are divided for convenience of description into the Oligocene, Fleming, and overlying sediments.

Oligocene fossils are reported to have been found in the Humble

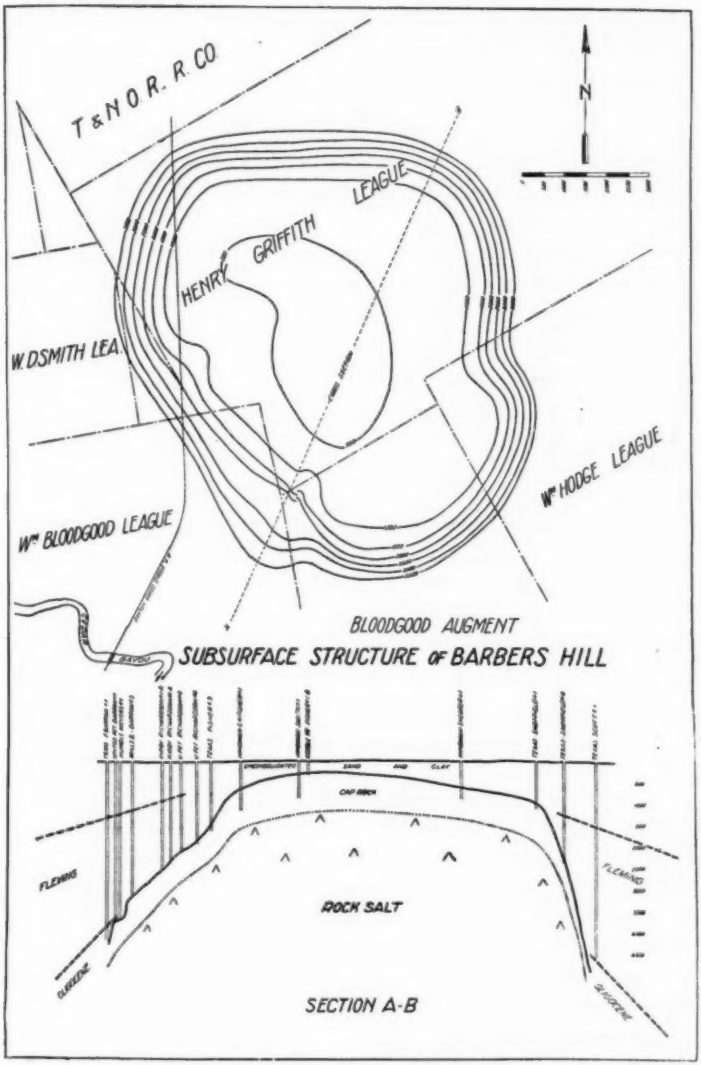


FIG. 2.—Map of subsurface structure of Barbers Hill with cross-section

Oil and Refining Company's No. 1 Meyers at 3,559 feet, indicating the top of the formation at this depth. This, to the writer's knowledge, is the only record of Oligocene formation at Barbers Hill.

The Fleming embraces the Miocene and a portion of the Pliocene formations. It is largely composed of calcareous clays with concretions, sands, and shales and is approximately 2,000 feet thick. These deposits are lenticular, extremely variable as to character, and change within narrow limits. The sandy members produce oil on the southwestern side of the dome.

Sediments overlying the Fleming and extending to the surface are of Pleistocene and Pliocene age. They consist, in part, of fluviatile and shallow-water deposits comprising a series of sands, gravels, and clays. These deposits are lenticular and extremely variable as to character. The thickness within the producing area averages about 1,400 feet, and the base of the formation dips at an angle of about 12°.

Geologic history.—The maximum structural displacement occurred at or about the transitional period between the Pliocene-Miocene deposition and continued with decreasing intensity to the time of Beaumont clay deposition. No observations have been made to establish the possibility of present-day growth.

Origin of the dome.—Barbers Hill is a typical salt dome. It was formed at about the same time and displays many of the characteristics common to other salt domes of the Gulf Coast district. Its origin is a subject upon which the writer has not observed any conclusive evidence to add to our present knowledge of salt-dome origin.

Origin of the cap rock.—The salt core of the Barbers Hill dome is intrusive, penetrating the surrounding formations. These formations have been cut or broken, permitting an intimate association of included waters with the salt plug. The water is under a static head, subject to minor movements of the dome, and has no doubt dissolved and redistributed a portion of the soluble material according to locally varying conditions and the laws of solubility. In view of this, it is believed that the mineralized material such as gypsum, anhydrite, cap rock, sulphur, etc., above the salt is derived from solutions as a precipitate or replacement, and that the character and extent of this material is governed by local conditions and subsequent movements of the dome. The presence of faulting within the

cap rock indicates that movement must have taken place after the cap rock was formed.

OIL DEPOSITS

Production is confined to an area of about 100 acres, located as shown on Figure 3, and represents about 5.8 per cent of the total

FIG. 3.—Property and well map of Barbers Hill

area of the mound. The oil is believed to originate within bituminous shales of the Oligocene and Miocene formations and to have later migrated into adjacent porous cap rock or sandy horizons. The majority of the so-called oil sands are really admixtures of sand, shale, and clay. They are lenticular, extremely variable as to char-

acter, and frequently change within narrow limits. Faulting is believed to play an important rôle in the accumulation of oil deposits and probably serves as an effectual barrier, retaining the oil on the downthrow side.

The character of oil varies considerably. Heavy oil of asphaltic base and thick consistency occurs in the upper portions of the cap rock and in sands adjacent to the cap rock. Oil of 17°–28° Baumé was produced from porous cap rock at depths of 1,065–2,230 feet within the older producing area. The gravity of this oil usually becomes lighter with depth, although exceptions to this rule have been noted. Oil produced from the edge sands around the dome range in gravity from 27° Baumé at depth of 2,730 feet to 39.7° Baumé at 3,817 feet.

Analyses of oil.—The following analyses are characteristic of the oil produced at Barbers Hill:

TABLE II

TEST ON TWO 5-GALLON CANS OF MIXED CRUDE OIL

Gravity	34.0
Flash	Room temperature
Fire	Room temperature
Vis., 100	43
Color	Dark green
Pour	Below 0
Sulphur	0.33 per cent
Water	None
Odor	Naphtha
B.S.	0.1 per cent

100 CC. DISTILLATION

Start	180
35 per cent off at	424
Overhead gravity	55.2
Color	Pure white
Doctor	N.G.
Bottoms	65 per cent
Gravity	25.4
Color	Dr. gr.
Pour	Below zero

Production curves.—A production curve has been prepared showing total monthly production from October, 1918, to December, 1923 (Fig. 4). Superimposed upon this curve is a second curve in

TABLE III

Cuts	Percentage	Temperature	Gravity	Flash	Fire Test	Viscosity	Color	Pour
1....	5	268	70.9	R.T.	R.T.	.....	S.G.	Below o
2....	10	315	62.8	R.T.	R.T.	.....	S.G.	Below o
3....	15	343	58.2	R.T.	R.T.	.....	W.W.	Below o
4....	20	360	53.6	R.T.	R.T.	.....	W.W.	Below o
5....	25	360	52.0	R.T.	R.T.	.....	W.W.	Below o
6....	30	368	49.0	R.T.	R.T.	.....	W.W.	Below o
7....	35	370	44.1	90	95	29	W.W.	Below o
8....	40	378	40.6	105	130	30	W.W.	Below o
9....	45	390	37.2	140	165	31	Lt. straw	Below o
10....	50	410	33.6	190	205	33	Lt. straw	Below o
11....	55	430	31.2	220	260	36	Lt. straw	Below o
12....	60	459	29.4	260	280	41	Straw	Below o
13....	65	485	28.0	290	310	52	Yellow	Below o
14....	70	512	26.5	310	345	69	Yellow	Below o
15....	75	545	24.8	355	400	135	Brown	Below o
16....	80	515	23.2	395	415	262	Dk. br.	Below o
Btms..	20	.....	18.4	510	575	238/212	Black	Plus 20

Estimated finished products: gasoline, 30 per cent; naphtha, none; kerosene, 15 per cent; solar oil, 35 per cent; bottoms, 15 per cent; fuel loss, 5 per cent.

TABLE IV

MIXED CAP-ROCK OIL; GRAVITY, 19°–20°

	Gravity	Flash	Viscosity at 100	Cold Test
1st.....	10°–29°7	155	10	.....
2d.....	10 –lost	.....	.....	.....
3d.....	10 –22.9	240	163–100	0
4th.....	10 –19.5	290	153–100	0
5th.....	10 –17.2	360	712–100	10
6th.....	10 –16.2	405	657–100	25
7th.....	10 –16.0	360	125–210	35
8th.....	10 – 1.59	245	126–210	30

Bottoms, 20 per cent.

broken lines, which indicates the fluctuations in price of crude oil.

A total of seven distinct peaks tell diagrammatically the story of the Barbers Hill production. The first three occurred in 1918, 1919, and 1920 and represent activities in the cap-rock field. The last four are records of edge-sand production during the years 1921, 1922, and 1923.

Maximum production for the field was reached in October, 1922. During this month a total of 53,800 barrels was produced largely from two wells: Mills Bennett, Japhet No. 1, and Japhet No. 2. The decline was very rapid, and within four months production had decreased 78 per cent.

The performance of individual wells is generally governed by the character of producing horizon, mechanical condition of the well,

Figure 5 shows production by months of Mills Bennett, E. Barrow No. 1, and Mills Bennett, Japhet No. 1.

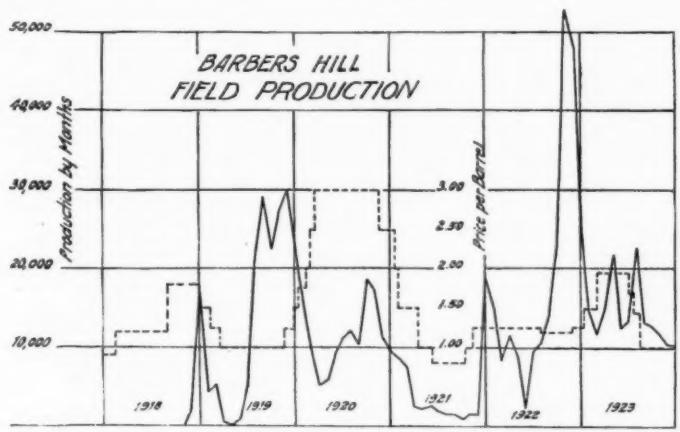


FIG. 4.—Curve showing Barbers Hill Field production

and method of operation. Cap-rock production is usually lower initially and less rapid in decline than production from edge sands.

Drilling and production methods.—All wells are drilled by the rotary method, using a fish-tail or roller bit as the occasion demands. Casing is usually set in gumbo or rock immediately above the producing horizon with from one to four joints of 80-mesh screen in the producing sand. The initial production of flowing wells is usually free from water or emulsion, but the oil from most of the wells eventually requires dehydration. The cost of drilling and completing a 3,000-foot well, including all items of expense, approximates $27,000.

SULPHUR

Showings of pure crystallized sulphur were found in a few wells along the southern slope of the hill. Jos. Reviere and Company drilled through sulphur and gypsum at a depth of 1,200 feet in their Reviere No. 1. Hindman *et al.*, Chambers County Agricultural Association No. 1, records sulphur, gypsum, and oil in hard rock at a depth of 1,380 feet. Community Oil Company's Monongahela Trust No. 1 obtained a little sulphur at 1,900 feet. Other wells of the vicinity are said to have shown sulphur while drilling through the cap rock.

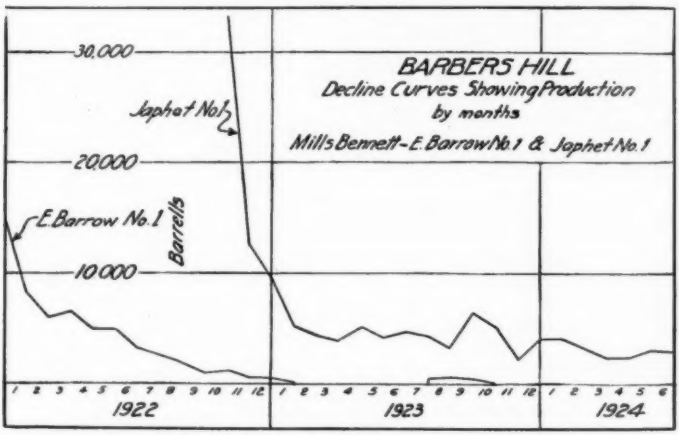


FIG. 5.—Curve of production decline, Barbers Hill Wells

All drilling prior to 1922 was primarily for the purpose of obtaining oil, and as a result very little was learned about the actual sulphur content of the formations penetrated. In 1922 the Union Sulphur Company and Sam Hindman *et al.* drilled ten wells on the dome in search of sulphur. These wells penetrated the cap rock for a considerable distance.

The sulphur occurs near the top of the cap rock and extends downward for several hundred feet. It is usually in the form of disseminated crystals deposited within porous limestone. The total sulphur content as indicated by core samples is not sufficient to warrant commercial exploitation.

CONCLUSION

It is apparent that the oil recovered at Barbers Hill has not been sufficient to satisfy the expenditure. Wells within an area outlined by the 1,000-foot contour, as shown in Figure 3, usually obtain shows of heavy, viscous oil from the top of the cap rock and in sands above the cap rock. The sands are thin, lenticular, and apparently broken. These horizons generally carry salt water containing relatively high percentages of hydrogen sulphide and very little oil.

Conditions favorable for the retention of oil occur within a small area on the southwestern portion of the dome. All attempts to extend this area or to locate a similar pool on other flanks of the dome have been unsuccessful. The steep dips encountered by these tests indicate that if additional production is found the oil will occur within a narrow strip surrounding the edge of the salt plug.

REFERENCES

1. *U. S. Geol. Surv. Bull. 282*, p. 83.
2. *Oil Investors Jour.*, Jan. 18, 1905; Oct. 19, 1907.
3. *U. S. Geol. Survey., Water Supply Paper 335*, p. 142.
4. *U. S. Geol. Surv., Mineral Reserves of the United States*, Part II (1916), p. 811.
5. *U. S. Geol. Surv. Bull. 429*, p. 12.
6. *Manufacturers' Record*, Vol. 71, May 24, 1917.
7. *Amer. Inst. Min. Eng.* (Feb., 1918), pp. 429–63; *ibid.* (May, 1918), pp. 987–1000; *ibid.* (Oct., 1918), pp. 1629–36.

RAINBOW BEND FIELD, COWLEY COUNTY, KANSAS

D. R. SNOW AND DAVID DEAN
Tulsa, Oklahoma

ABSTRACT

The Rainbow Bend oil field is located near the west line of Cowley County, Kansas, about midway between Arkansas City and Winfield. Since its discovery in December, 1923, over 2,000,000 barrels of oil testing about 41° gravity Baumé have been produced. The oil comes from sand at the very base of the Pennsylvanian, and production appears to be controlled by the distribution of this sand, which is lenticular. A well-defined, anticlinal dome is defined by the top of the Mississippian limestone, the oil sand occurring on the southeast flank of this fold. Development is controlled by one company, and there is consequently no overdrilling. Casinghead gasoline is an important product from the wells.

The Rainbow Bend field of Cowley County, Kansas, is the first field of commercial importance to be opened between the old Augusta and Blackwell oil fields. Since its discovery in December, 1923, the field has produced over 2,000,000 barrels of oil of approximately 41° gravity Baumé. Thirty-one wells have been completed with an average daily initial production of over 1,000 barrels per well without shooting. The field is now making around 12,500 barrels daily. There are 28 drilling wells, most of which are inside proved locations, and from present indications the field gives promise of developing into one of considerable importance.

A much higher daily output would undoubtedly have been reached but for the fact that the entire block is owned and controlled as a unit by three companies. Waite Phillips Company, which owns a half-interest, operates the property. The Marland Oil Company, and the Independent Oil and Gas Company, each own a one-quarter interest.

The writers have watched the development of the field in the interest of Waite Phillips Company and are indebted to them for the privilege of presenting this paper.

LOCATION

The Rainbow Bend field is located in T. 33 S., R. 3 E., Cowley County, Kansas, in the center of a 3,500-acre block which occupies a large bend in the Arkansas River, locally known as Rainbow Bend —hence the name of the field.

HISTORY

Mr. Martin W. Baden, of Winfield, originally assembled this block and made a favorable geological report to Mr. Johnson D. Hill, of Okmulgee, who jointly with the Independent Oil and Gas Company contracted to drill a 3,000-foot test. When Mr. Hill became affiliated with the Waite Phillips Company in 1923, this company acquired his half-interest in the project.

Nothing was found at 3,000 feet, and the well was drilled deeper, topping the pay at 3,198 feet, and the discovery well was completed in December, 1923, as a 350-barrel flowing well.

Several months later the Marland Oil Company purchased one-half of the Independent's half-interest, and laid a pipe line to the field from their Ponca City refinery. This line has taken all of the oil from the Rainbow Bend field until recently when Waite Phillips Company started running part of their production to their own refinery at Wichita.

Several of the larger companies, recognizing the importance of the discovery, moved core drills into the area, and as a result the Marland Oil Company located and drilled their Graham No. 1, in the northeast corner of Sec. 9, T. 33 S., R. 3 E., 3 miles northeast of the Rainbow Bend field. This well found only a sandy shale in the Rainbow Bend producing horizon, but it was completed in July, 1924, as a 900-barrel well in the top of the Ordovician siliceous limestone. This was the first commercial producer found in this horizon in Cowley County. Eight wells have since been completed in this field, which is known as the Graham field, and there are at present 15 drilling wells in this vicinity. Several wells have also been completed in this area in the 2,550-foot sand.

GEOLOGY

SURFACE INDICATIONS OF STRUCTURE

Surface rocks in the Rainbow Bend area are chiefly alluvium, shale, and red rock. Evidence of surface structure is confined

principally to a rotten, brecciated limestone which weathers into a very characteristic porous outcrop. This bed lies in the upper part of the Pearl shales about 70 feet above the Herington limestone. This is near the contact of the Marion and Wellington formations, which are of Permian age. This limestone, probably occupying the stratigraphical position of the Abilene conglomerate, can be followed from the north line of Sec. 7, T. 33 S., R. 3 E., southeast for about 3 miles along the west side of the river into the center of the southwest quarter of Section 20, of the same township.

No appreciable structure is evident on this ledge, the dips being irregular and the greatest difference of elevation being but 15 feet. However, 1½ miles southeast under the river bridge in Section 21, there occurs a limestone bed of practically the same physical characteristics which is 20 feet lower in elevation than the bed in the Rainbow Bend. No fossils have been found in either of these limestone outcrops, and a definite correlation has not been made, but it is the writers' opinion that they are the same. As far as we know, this is the only surface evidence of a structure in Rainbow Bend.

STRUCTURE SHOWN BY CORE-DRILL

Waite Phillips Company has done no core drilling in this area, but from authoritative sources, it is understood that the Herington limestone shows a long, southwest-plunging nose whose axis conforms generally with the Mississippi lime axis through the Graham and Rainbow Bend fields, but whose dips are much less pronounced than those on the deeper formations.

SUBSURFACE STRUCTURE

The subsurface structure of this district, as shown on the general map in 50-foot contours on the top of the Mississippi lime (Fig. 1), indicates an axis of folding from the Clarke field in Sec. 6, T. 31 S., R. 4 E., extending south through the Rainbow Bend field to Blackwell. This same trend probably extends south through the Hubbard, Bezdor, and Barnes fields to Garber. It is approximately parallel to a line drawn along the axis of the Granite Ridge and is probably closely associated with it in origin, although no granite has been found south of Oxford on this trend.

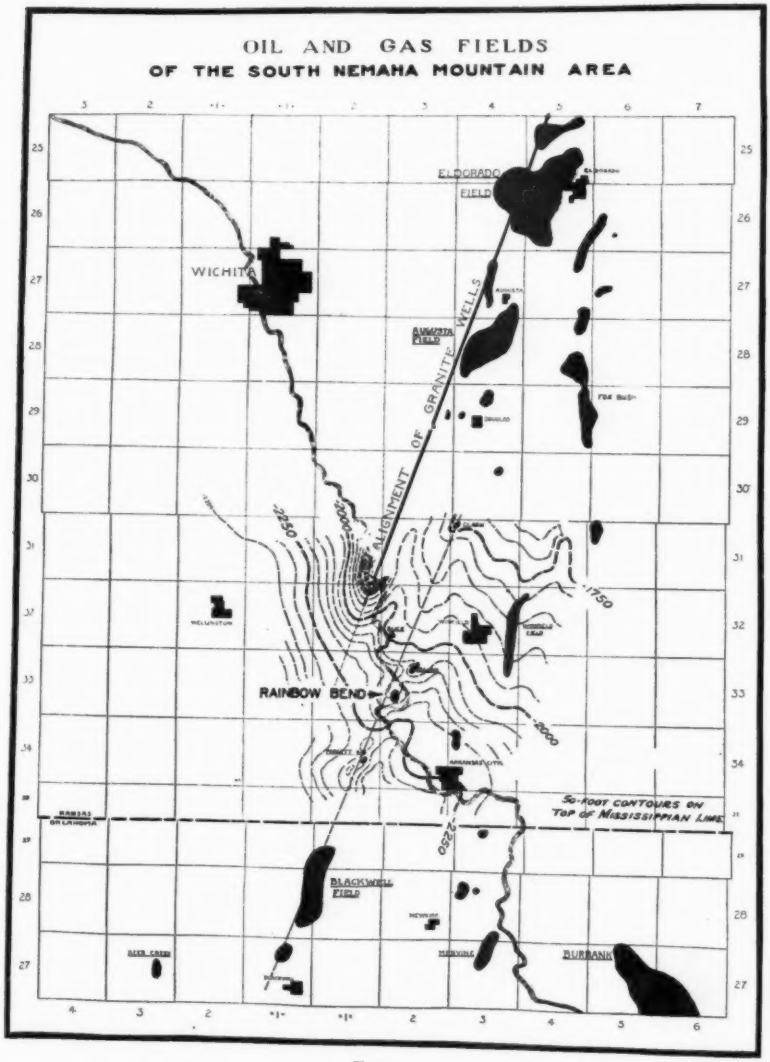

OIL AND GAS FIELDS
OF THE SOUTH NEMAHA MOUNTAIN AREA
ELDORADO FIELD
WICHITA
AUGUSTA FIELD
ALIGNMENT OF GRANITE WELLS
RAINBOW BEND
BLACKWELL FIELD
BURBANK
-2250
-2000
-1750
-2000
-2220
50-FOOT CONTOURS ON TOP OF MISSISSIPPIAN LIME

FIG. 1

Along this general axis of folding, isolated structures of various types occur, of which the Graham and Rainbow structures are fair types. On the accompanying large-scale map (Fig. 2), 10-foot contours have been drawn on top of the Mississippi limestone, defining these structures as far as is known by present drilling. There is considerable question concerning the contouring in Sections 7 and 8, and it is impossible to determine from present available data whether this area is synclinal or anticlinal, but we are influenced by the Slick and Marland's Heskett well in Section 19, which is running high, in drawing in an anticlinal fold south of the Patterson dry hole in Section 18.

Another interesting fact in connection with subsurface observations of this area is the variation in thickness of the Mississippi limestone with relation to structure. On the south and east sides of the field the lime is 100 feet thicker than on the crests of the folds. This causes much steeper dips on the Ordovician limestone than are shown on top of the Mississippian. A similar but not so pronounced variation is found in the Cherokee shale.

PRODUCING HORIZONS

Three producing sands are at present known in T. 33 S., R. 3 E. The shallowest, found at 2,550 feet in the Graham field, appears to be a spotted producer. Good showings have been found at this horizon in the Rainbow Bend field, but no producers have been completed. This sand is producing in the Slick pool 6 miles north. It lies in the upper sandy member of the Kansas City formation, and correlates with the Layton sand of Oklahoma, and the Stokes sand at Eldorado.

The second sand, and the most important, is found on top of the Mississippi lime and has been termed the Rainbow Bend sand. It has been thought better to name the producing horizon from the name of the field as at Burbank rather than from the farm on which the discovery was made. The writers believe that this sand can be referred consistently to the Burbank sand horizon of Oklahoma which has previously been correlated with the Bartlesville. These three sands apparently occupy the same horizon, although they

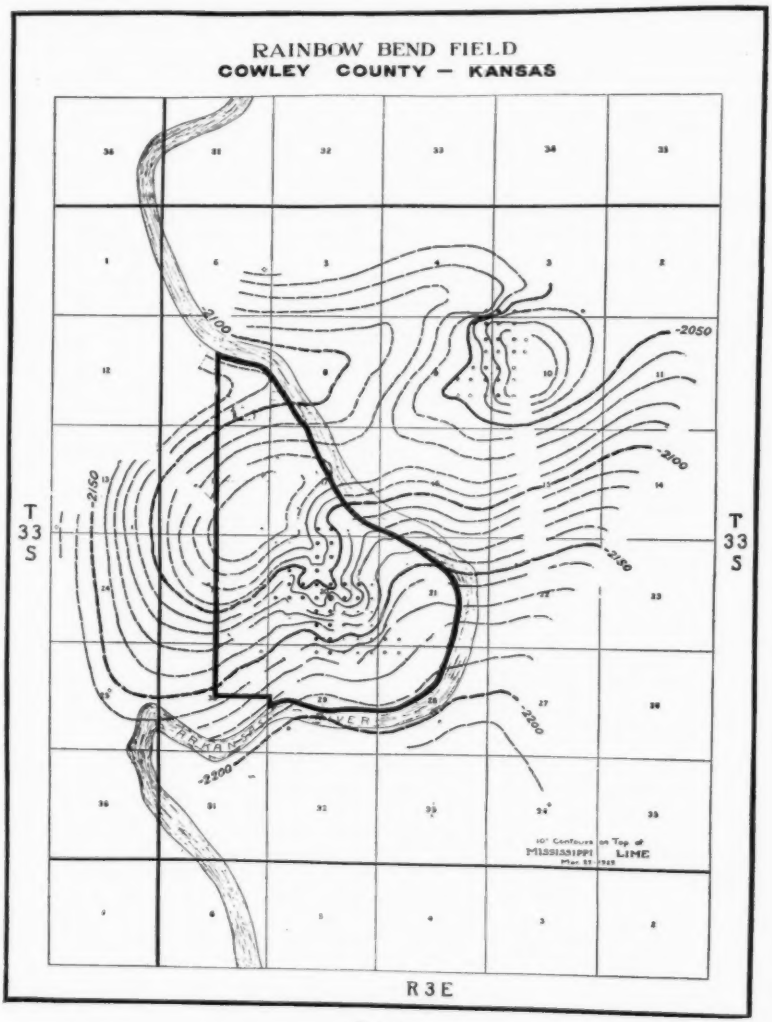

RAINBOW BEND FIELD
COWLEY COUNTY — KANSAS
-2100
-2050
-2150
-2200
T 33 S
R 3 E
10' Contours on Top of MISSISSIPPI LIME

FIG. 2

cannot be shown to be continuous, and are therefore given separate names.

A cross-section from Burbank to Rainbow Bend shows that this sand is closely associated with a red-rock horizon, and that the thinning of the shale below the sand to the northwest has brought the sand in contact with the Mississippi limestone in the Rainbow Bend field.

The Rainbow Bend sand is a true quartzitic sand of varying hardness, depending largely on the amount of calcareous cementation. One specimen of this sand was obtained from the Glasgow No. 5 well on the west side of the field, and showed a porosity of 29 per cent, which is unusually high. This porosity is probably not representative of the field, as the sample was obtained when a gas pocket blew the sample of sand out of the hole.

The thickness of the Rainbow Bend sand varies from 5 to 50 feet, thinning toward the crest of the Mississippi lime ridge and thickening toward the southeast. No water has yet been found in its base. Some water has shown in those wells which have been drilled several feet in the Mississippi limestone.

The next important sand occurs at 3,500 feet in the top of the Ordovician siliceous limestone. In many wells which have tested this horizon a thin film of Wilcox sand and green shales have been found between the Ordovician limestone and the Chattannooga shale. This productive siliceous limestone bears the same characteristics as at Eldorado and Augusta and presents a similar problem of closely associated sulphur water. At present, this horizon is only producing in the Graham pool.

RELATION OF PRODUCTION TO STRUCTURE

Production in the Rainbow Bend field is very similar to that in the Burbank field in that it is controlled almost entirely by the character and extent of the sand body. The largest wells occur on that part of the fold where the sand is thicker and more porous, which occurs from 30 to 50 feet below the highest parts of the sand body.

The sand in the Rainbow Bend field lies on the southeast slope of a prominent Mississippi lime ridge, and as far as we know this is

the only occurrence of a productive sand body lying to the east of a lime high in this general area. The extent of this sand body will probably define the limits of the field.

Ordovician siliceous lime production will probably bear the same relation to structure here as at Eldorado and Augusta. So far, this production has not given promise of any real importance, but the Marland Sheehan well in Section 34, which ran 297 feet lower than the Graham discovery well, and showed for a 40-barrel pumper, suggests that this sand has possibilities of producing over a much larger area than is included in the present Graham field. One well in the Rainbow Bend field, the Patterson No. 1, has recently been drilled to this horizon without finding production.

PRODUCTION YIELD PER ACRE

For the area already proved, approximately 640 acres, the probable yield per acre will be about 12,000 barrels. This is considerably greater than the average yield per acre at Burbank, but the natural initial production per well in the Rainbow Bend field is also much larger than the average for the whole field at Burbank. As the proved area increases, this estimate per acre will probably be reduced because of poorer production on the edges of the field, and the relief of gas pressure through present producing wells.

CASINGHEAD-GASOLINE PRODUCTION

A casinghead-gasoline plant has recently been completed, and is producing approximately 15,000 gallons per day. This plant is being enlarged to a capacity of 30,000 gallons per day. There are approximately 25,000,000 cubic feet of casinghead gas available from the Rainbow Bend sand at the present time. The average yield per thousand cubic feet of gas is now about 2.0 gallons of Grade A gasoline, and will no doubt greatly increase as the field increases in age. It is estimated that the plant can be operated at a capacity of 30,000 gallons per day for two and one-half years from the gas of the present proved area before production will be decreased from diminished gas. It is also estimated that the value of the casinghead-gasoline production is approximately 25 per cent of the value of the oil production.

DISCUSSION

C. N. GOULD: Is it not true that at the type location the Abilene formation is a mud or clay conglomerate?

E. C. PARKER: This bed in the type section at Abilene, Kansas, at the few exposures where it is unaltered is a soft, gray limestone about 2 feet thick. The interval down to the top of the Herington limestone varies from 40 feet at Abilene, Kansas, to about 50 feet at Ponca City, Oklahoma.

In the majority of exposures this calcareous material has been partly or wholly dissolved and redeposited in the same horizon, often with gypsum derived by solution from strata higher in the section. Due to this mode of origin, pieces of the green shale above the Abilene limestone (as it might better be named) have been included in some places in this massive bed of secondary limestone. It can no more be called a conglomerate than the top member of the Herington, which is often similarly altered at the type vicinity.

March, 1925

THE EXTENSION OF A PORTION OF THE PONTOTOC SERIES AROUND THE WESTERN END OF THE ARBUCKLE MOUNTAINS

RALPH A. BIRK
Ardmore, Oklahoma

ABSTRACT

The limestones near the base of the Stratford formation of the Pontotoc series have been traced around the west end of the Arbuckle Mountains, and then southeast to a point near Ardmore. This mapping was done before George D. Morgan's report on the "Geology of the Stonewall Quadrangle, Oklahoma" was published; and since the top, rather than the bottom, of the limestone series was followed, the line shown on the map does not coincide with one of Morgan's formation boundaries. The base of the Asher formation, which is next above the Pontotoc series, was also traced around the mountains and found to overlap the shale in the upper part of the Stratford formation. At the west end of the mountains the Asher formation rests directly on the limestones in the lower part of the Stratford formation, which are in contact with the upturned edges of the Ordivician limestones; all lower members of the Pontotoc series are absent. The conglomerates near Berwyn, formerly called Franks, are assigned to the Pontotoc series, and a correlation made across the mountains by J. T. Richards on the basis of some concentric-ringed pebbles which have been banded by algae. It is suggested that the uncertain boundary between the Permian and Pennsylvanian be placed at the base of the Asher formation.

INTRODUCTION

A few months ago the writer had occasion to do some mapping on the limestones exposed in T. 1 S., R. 2 W., Carter County, Oklahoma, north of the village of Pooleville and around the shallow Homer oil field in Sections 8, 9, and 16. This township is located at the western end of the Arbuckle Mountains, and while working there it was found that the limestone formation continued for some distance around both the northern and southern edges of the mountains. It was thought at that time that these limestones could be traced far enough north and east to be correlated with those which outcrop about 15 miles east of Pauls Valley.

Quite recently it has been my good fortune to spend several days in field conference with Mr. H. D. Miser, of the United States Geological Survey, in connection with his work on the new areal geologic map of Oklahoma. During this conference the top of the lime-

stone formation at the western end of the mountains was mapped as far east as the west side of the Stonewall quadrangle, and the formation was correlated with those limestones which outcrop southwest of Stratford. These outcrops are described by George D. Morgan[1] as "about 100 feet of impure limestones" in the middle division of the Pontotoc series. In a more recent report,[2] Morgan places these limestones in the Hart limestone member of the Stratford formation. A massive sandstone ledge which is normally several hundred feet above the limestone formation, was followed for some distance and found to overlap the shale between the two formations. A section through these two formations at the northwestern end of the mountains has been described by E. R. Brockway and H. J. Owens.[3]

The writer is especially indebted to H. D. Miser for his cooperation in the mapping of these formations; to J. T. Richards for his notes on the Berwyn conglomerate which are incorporated under that heading; and to C. W. Tomlinson for his work in mapping the limestone conglomerate and arkose between Milo and Ardmore. Thanks are due C. E. Decker for permission to use his unpublished map of the western part of the Arbuckles, and to E. A. Obering for the compilation of the present map (Fig. 1). Publication is by permission of the Amerada Petroleum Corporation.

HART LIMESTONE

The Hart limestone member of the Stratford formation has been more carefully studied by the writer in T. 1 S., R. 2 W., than in any other locality, but it is thought that the outcrops in that township are typical of the formation as it is exposed on both the north and south sides of the Arbuckle Mountains. The limestone consists of massive but lenticular beds of limestone and shale, with some limestone conglomerates, beds of arkose, and a few asphaltic sandstones. The limestones vary in color from white through a yellowish brown and from gray to black. They are non-fossiliferous, except at a locality in sec. 10, T. 1 S., R. 2 W., reported to the writer by Rud. Brauchli, and seldom contain bedding planes or lines of cleavage.

[1] "Arkose of the Northern Arbuckle Area," *Okla. Geol. Surv. Circular*, No. 2.

[2] "Geology of the Stonewall Quadrangle, Oklahoma," *Bur. of Geol. Bull. 2*.

[3] E. R. Brockway and H. J. Owens, "Notes on the Area Lying between the Northwest Edge of the Arbuckle Mountains and the Wild Horse Sandstone," *Okla. Acad. of Sci. Bull.*, Oct. 1923.

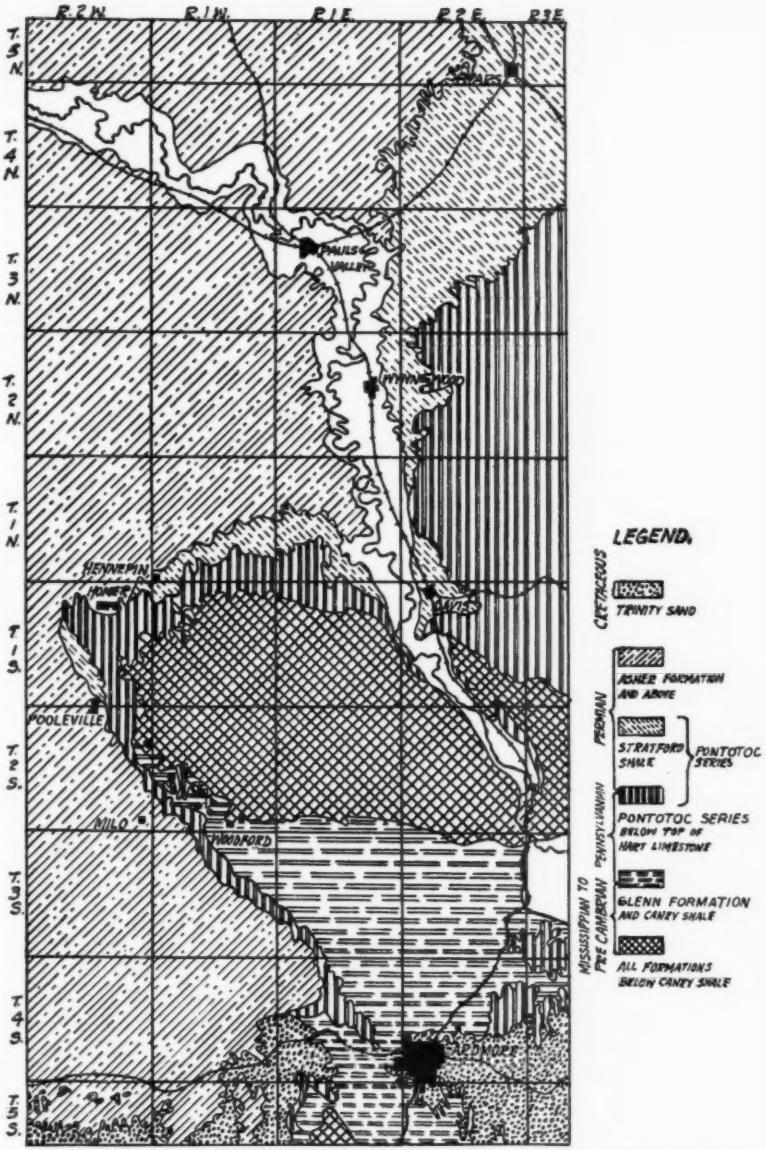


FIG. 1.—Extension of a portion of the Ponotoc Series around the west end of the Arbuckle Mountains. Scale 1 in. = 8 mi.

The limestones are secondary and were formed with reworked material from the Ordovician limestones in the Arbuckle Mountains. In a great many places they weather out so as to be identical in appearance with the Ordovician. The beds of limestone change in thickness abruptly. An illustration of the rapidity with which these lime beds may thin out is shown by the following observations. In Sec. 9, T. 1 S., R. 2 W., logs of the shallow wells show from 50 to 200 feet of solid lime, and there is about 40 feet of almost solid lime exposed at the surface. About 4 miles to the east, where the limestone formation overlaps the west end of the mountains, the limestone beds are about 10 feet in thickness and are interbedded with red shale. They also seem to thin out rapidly farther away from the mountains, as evidenced by a study of the well logs, although the Weaver and Reynolds well in Sec. 24, T. 1 N., R. 2 W., had 200 feet of this lime at 1,165 feet.

The top of the Hart limestone member has been traced from the SW. cor. of Sec. 33, T. 4 N., R. 3 E., on the west side of the Stonewall quadrangle, southwest toward Davis, where it is deflected a little to the southeast by the Mill Creek syncline. It then continues west along the north flank of the Arbuckle Mountains to the shallow oil field at Homer. Here it bends sharply to the southeast and forms part of the plunging anticline on which the Homer field is located. It continues southeast past Pooleville, gradually swinging away from the mountains, and passes between Milo and Woodford. About a mile south of Woodford the limestone disappears beneath a deposit of river gravel, but a few miles farther along the trend of the limestone formation, a series of arkoses and arkosic limestone conglomerates are found which were mapped to a point 2 miles west of Ardmore. One thin limestone ledge was found in the series a short distance west of Ardmore. It is thought that this arkosic series is a little below the lime formation in the stratigraphic section. There is a small strip of arkose around the north end of the Criner Hills which is correlated with the arkosic series west of Ardmore on account of the similarity in appearance, and the large amount of feldspar that is present in each place.

This strip of arkose at the north end of the Criner Hills and the large area of arkose and conglomerate south of Berwyn are shown on the map of Carter County in the *Oklahoma Geological Survey Bulletin*

19, Part 2, as Franks conglomerate. J. T. Richards has been working on the Berwyn conglomerate, and, although he is not ready to make any very detailed report, he has kindly furnished the author with a short description of the formation and a very interesting correlation across the mountains.

BERWYN CONGLOMERATE

South of the town of Berwyn, Carter County, Oklahoma, is an area covered with a series of limestone conglomerates, arkosic sandstones, dark shales, and thin limestones, here named the Berwyn conglomerate. Banded pebbles which form a part of the limestone conglomerates occur in this series at several horizons. These pebbles vary in size from a fraction of an inch to a maximum of 3 inches in length. At first they were taken to be concretions, due to their banded structure and the fact that the bands are built up around nuclei which vary widely in composition. The most common material is limestone recognizable as representing the older limestones of the Arbuckle Mountains. Granite, chert, and other fragmentary materials are not uncommon. The shell on these pebbles varies from $\frac{1}{8}$ inch to 2 inches in thickness.

Pebbles of a similar nature have been found on the south side of the mountains in the following localities: 1 mile north and 2 miles west of the town of Ardmore; near the town of Deese in Sec. 4, T. 4 S., R. 1 E., and on the north side of the mountains near the center of the south line of Sec. 36, T. 1 N., R. 2 E., halfway between Sulphur and Davis.

These pebbles were at first regarded as concretions, but in a communication from Dr. E. O. Ulrich he says:

> The concretion-like pebbles were closely investigated and the conclusion finally reached was that they are of organic nature—that is, they are calcareous laminae deposited by successive layers of algae. These evidently grew on and between the pebbles of the conglomerate in which they occur.[1]

South of the Arbuckle Mountains the series rests unconformably on the Glenn formation (Pennsylvanian) and is overlapped by the Trinity sand (Comanchean). An effort was made to trace the outcrops from the area near Berwyn into the arkosic series northwest of Ardmore but this proved futile. The concretionary beds probably

[1] Personal communication to H. D. Miser.

swing to the south. The eastern and western limits have not been determined definitely. North of the mountains the relation of the series to the underlying formations was not determined. The areal extent in this region was left for future determination.

A study of Morgan's report of the "Geology of the Stonewall Quadrangle, Oklahoma" indicates that the outcrops of banded pebbles found on the north side of the mountains fall well within the limits of his Vanoss formation. He describes this formation as consisting of alternating sandstones, conglomerates, shales, and a few thin limestones. All the strata are arkosic.[1] These characteristics are dominant in all areas where the banded pebble series is found. Morgan gives no detailed description of the conglomerates which he assigns to the Vanoss formation but shows a picture of one of these conglomerates 1 mile east of Sulphur.[2] The author visited this neighborhood and found some pebbles which had very thin banded shells but no pebbles with thick shells such as were found in the other locations mentioned.

With the foregoing data at hand the following conclusions have been reached: (1) The banded pebbles here described were formed under a peculiar and definite condition. (2) They form a basis of correlation of beds on the north and south sides of the Arbuckle Mountains. (3) The beds containing these pebbles on the north side of the mountains are a part of the Pontotoc terrane as described by Morgan and probably belong to the Vanoss formation. (4) The beds south of the mountains, containing the banded pebbles, are of the same age as those north of the mountains.

STRATFORD FORMATION

The higher formation which was mapped around the western end of the Arbuckle Mountains is a massive gray, manganiferous sandstone which forms an escarpment about 50 feet above the contact between the typical red beds and the chocolate-colored shales of the Stratford formation. A typical exposure of this bed can be seen at the abandoned copper mine in the SW. $\frac{1}{4}$ of Sec. 35, T. 5 N., R. 2 E., southwest of the town of Byars. There are about 50 feet of purple shale above this formation and below a massive, yellow sand-

[1] *Bur. of Geol. Bull. 2* (Norman, Okla., 1924), p. 133.

[2] *Op. cit.*, Plate 19.

stone which E. R. Brockway[1] has called the Wildhorse sandstone. These purple shales and the black manganese stains in the sandstone below form well-defined markers that persist as far as the bed has been traced. This sandstone is thought to be that described by Morgan[2] as the base of the Asher formation which outcrops on the north bluff of Canadian River at the bridge south of the town of Asher.

The basal sandstone in the Asher formation was traced from a point west of Byars and south of Canadian River, southwest to Pauls Valley, and along the west side of Washita River to the mouth of Wildhorse Creek. It then turns along the north side of the creek and strikes west on a line that is roughly parallel with the mountains. It gradually overlaps the shale intervening between it and the Hart limestone member, and in Sec. 1, T. 1 S., R. 2 W., it is found directly above the lime. A section showing the unconformity can be seen on the north line of Sec. 1, T. 1 S., R. 2 W., where the main highway southwest of Hennepin crosses Eight Mile Creek. From this point on around the west end of the Arbuckles the Asher sandstone is resting on the Hart limestone member, except for a strip of the intervening shale that is exposed in the center of T. 1 S., R. 2 W.

The average dip of the Hart limestone at the west end of the mountains is 120 feet per mile, while that of the Asher sandstone is from 20 to 40 feet per mile. There is an angular unconformity between the overlapping limestone and the steeply dipping rocks in the Arbuckle Mountains, and also between the lime and the Glenn formation (Pennsylvanian) on the south side of the mountains.

The oil in the Homer shallow field is found in sand breaks in the Hart limestone member at an average depth of 200 feet. The gravity is 24.8° (A.P.I.), but there is a high lubricating content (65 per cent). There is no pipe line, but some of the oil is carried to Davis by truck and shipped. Present price (February, 1925) is $3.50 net. The potential daily production of the field is 150 barrels from 41 wells.

Morgan places the Pennsylvanian-Permian contact at the base of the Hart limestone member of the Stratford formation although his evidence consisted of one plant possil of somewhat doubtful age. It is the writer's opinion that the contact should be placed at the upper limits of the Stratford shale or the base of the typical red beds.

[1] *Loc. cit.*

[2] *Ibid.*

THE AGE AND CORRELATION OF THE KREYENHAGEN SHALE IN CALIFORNIA

G. D. HANNA
San Francisco, California

ABSTRACT

The Kreyenhagen shale at the type locality on Canoas Creek, Fresno County, California, is Eocene in age. The siliceous, diatomaceous shale north of Coalinga, lying above an Eocene sandstone and usually referred to the Kreyenhagen of late years, is not the equivalent of the original deposit given that name and may be the same as what is called Oligocene or Lower Miocene elsewhere in the state.

In the undertaking of microscopical studies of the rocks of various geologic ages in California the plan has been followed of securing representative material from type sections of the various formations whenever possible. In this manner it was believed that species of fossils would be obtained which would prove to be most reliable for comparison of material derived from sources unknown or questionable. Thus the section at Monterey was visited to secure species of undoubted Miocene age; Grapevine Canyon and vicinity furnished a Tejon fauna which cannot be challenged; the exposure of rocks at Martinez gave the lowest member of the Eocene without a chance of mistake; etc. These typical collections prove to be invaluable in the identification of such material as is obtained in large quantities in the drilling of oil wells.

The following out of this plan led to a search for material from Oligocene, which for a number of years has been reported to exist rather extensively in California.

The strata first described in the state which have been given a name and were later referred to the Oligocene are located in western Fresno County and were called Kreyenhagen shales by F. M. Anderson.[1] True, he called the formation Eocene, but since 1915,

[1] *Proc. Calif. Acad. Sci.*, Vol. 2 (3d series, 1905), No. 2, p. 163.

[2] *U. S. Geol. Surv. Bull.* 603, 1915.

when Robert Anderson and R. W. Pack made an extended study of the geology of that region,[2] it has been referred to almost continuously as Oligocene. These authors, however, were careful to put a question mark after the name, showing that they were not thoroughly convinced in their own minds as to the age of the rocks.

It seemed that the type locality of the Kreyenhagen shales should offer an opportunity of securing a correct idea of California Oligocene if any place would. But difficulties were encountered very soon, as will be seen from the following paragraphs. The type locality of the Kreyenhagen shales is on Canoas Creek in southwestern Fresno County, California. The formation is a bed of shale about 1,000 feet thick, below undoubted Miocene sandstones and above others reported to be of Eocene age. The land has long been known as a part of the Kreyenhagen ranch, and a few wells bearing the same name have been drilled into the formation at the type locality.

The original description is as follows:

> While the stratigraphic divisions of the Eocene do not continue regularly throughout, there is at least one member that is fairly well characterized along the whole extent of the series as far as has been followed. This member is the middle one, and consists of brown bituminous or carbonaceous shale, more or less sandy in the lower portion, and with a maximum thickness of 600 feet as exposed on the hills a few miles north of Coalinga. Farther to the south and southeast it varies considerably, attaining at the Kreyenhagen wells a thickness of about 900 feet, while on the head of the Jacalitos and on the Zapata Chino there are not more than 250 or 300 feet of strata. On account of its development at the Kreyenhagen wells this member of the Eocene has been termed the *Kreyenhagen shales*. The lithological character of these shales is not constant, as the proportions of the chief elements vary from point to point. Sands, clay, and organic matter, both calcareous and carbonaceous, make up the mass of the beds, which at some points become sandy and at others argillaceous, while the percentage of lime or carbonaceous matter also varies.
>
> Nodular masses of calcareous rock and nodules of barites ($Ba\,SO_4$) are common in many places, and these form a characteristic feature of the shales.
>
> The calcareous masses occurring in the shales often contain Foraminifera in great numbers, not unlike certain rocks of the Miocene. The brown color of these shales is probably due in large part to bituminous matter contained therein; but this will be referred to later [pp. 163–64].
>
> On the northeast quarter of section 17 north of Coalinga, similar pebbly beds just above the top of the Kreyenhagen shales contain a few of the foregoing species (undoubted Eocene Mollusca) along with species of Foraminifera and nodules of barite [p. 167].

The stratigraphic members of the Eocene, then, are the following:

Domijean sands
Kreyenhagen shales
Avenal sandstone [p. 168]

For the purpose of calling attention to the many well-preserved forms of Foraminifera in the Eocene rocks of the Mount Diablo Range, and to illustrate some of the more common genera, a few have been figured [Plate 13, Figs. 9–29] without any attempt at specific identification, along with other Eocene species occurring in very nearly the same horizon. These Foraminifera are as follows:

Nodosaria	*Cyclammina*
Lagena(?)	*Pulvulina* [*Pulvinulina*]
Sagrina	*Polymorphina*
Vaginulina	

Some of the species of Foraminifera are very large, and can be easily seen with the unaided eye. Some species of *Nodosaria* attain a length of three-fourths of an inch, and all of them are easily distinguished with a good lens. Most of the forms are found in calcareous concretionary masses, occurring as lenses in the argillaceous beds described in this paper as the Kreyenhagen shales [pp. 192–93].

This appears to be a sufficiently clear statement of the facts to enable the formation described to be recognized subsequently. The author left no doubt as to the position of the shale at the type locality above a massive sandstone named Avenal. It was his belief that the age was Eocene although he offered no paleontologic proof. His fossils were collected many miles to the north and are, in most part, of unquestionable Eocene age. The block containing most of those pictured in his report is preserved in the California Academy of Sciences. The large *Nodosaria* mentioned and the *Cristellaria* (Fig. 19, Plate 13, called *Vaginulina*) appear to be confined to that portion of the Eocene in California above the middle. The species which he identified and pictured as *Sagrina* came from the upper part of the Cretaceous shales which, north of Coalinga, at some places underlie the Eocene shales with no apparent unconformity or change except in faunal content.

Attention is now particularly called to the fact that F. M. Anderson described the Kreyenhagen shales as (1) brown, bituminous or carbonaceous; (2) sands, clay, and organic matter, both calcareous and carbonaceous, make up the mass of the beds; (3) the shales contain barite; (4) lenses at some points contain Foraminifera now definitely identified as Eocene. Most of this information was apparently derived from the section north of Coalinga and not from the

type locality on Canoas Creek. If by any chance or rule it should be decided that the locality north of Coalinga must be considered the type locality of the Kreyenhagen shale because it happened to be the first locality mentioned in the author's description of the formation, then there can be no possibility of contesting the Eocene age. The fossils he mentioned and figured from there and the position of the deposit beneath fossil-bearing sandstone of Eocene age leave no doubt as to age.

The same author in his second paper on the same region[1] continued the same classification of the Eocene although he did not refer specifically to the type locality of the Kreyenhagen shales. Unfortunately, in this publication he injected another deposit of shale into the Eocene provisionally, a deposit found north of Coalinga and overlying his other three divisions. This he summarized as follows:

> As to the definite assignment of these shales to either the Eocene or the Oligocene in the time scale of California geology, that must be reserved for further study and for some future time. Stratigraphically and structurally they are certainly connected closely with the Tejon series, while faunally they are allied more closely to the Miocene.

He assigned this bed a thickness of 1,800 feet on Cantua Creek with progressive thinning to the southward to 600 feet near Oil City, with subsequent disappearance entirely within a short distance. The upper part is stated to contain many diatoms and Foraminifera, and one mollusk, *Pecten peckhami* Gabb, is identified.

It is this latter deposit of shale, which he had previously referred to the Miocene along with other authors, which has caused the confusion now existing regarding the application of the name Kreyenhagen shale, as will presently appear.

Arnold and Robert Anderson in 1910[2] redescribed the original locality on Canoas Creek although they did not refer the formation to F. M. Anderson's name. Their description, being more complete than any other available, is quoted as follows:

> The shale overlying the sandstone of the Tejon is less resistant to weathering [than certain Cretaceous shales previously considered] and forms a belt of low topographic relief between the line of peaks formed by the lower sandstone

[1] *Proc. Calif. Acad. Sci.*, Vol. 3 (4th series, 1908), pp. 12–15.

[2] *U. S. Geol. Surv. Bull. No. 398* (1908), p. 69.

and the sharp ridge of the Vaqueros [Lower Miocene] "reef beds." This belt is marked by few outcrops and is almost entirely bare of vegetation except grass and scattered small juniper and oak trees. It is only in the canyons that the rocks of this zone are well exposed, and there they are seen to be chiefly thin beds of purple shale, steeply tilted and considerably fractured and distorted. At the base the beds of this member are almost invariably poorly exposed, but they seem to be somewhat sandy through a thickness of about 200 feet, as if representing a transition from the sandstone of the lower member. Above this transition zone the beds are fine-grained argillaceous and siliceous shale of a peculiar dark purplish brown, and similar to some of the shale in the upper member of the formation north of Coalinga. Thin laminae of fine sand are occasionally intercalated. The shale is usually comminuted into fine flakes or locally almost into a powder. It has a black carbonaceous appearance in places, this and the purple color possibly being due to the impregnation with petroleum. The cracks in the shale are frequently lined with sulphur. Toward the top the shale becomes yellowish or whitish in places, for example, near and southeast of Big Tar Canyon, and both siliceous and calcareous, the latter variety containing innumerable Foraminiferal remains. These beds bring out still more strikingly the resemblance to the shale member north of Coalinga, and indicate that the same horizon is represented in both localities. The thickness of beds exposed between the sandstone of the Tejon and the Miocene varies from place to place along Reef Ridge. The maximum thickness that has been found is in the neighborhood of Canoas Creek where it is about 1,000 feet.

It will thus be seen that Arnold and Robert Anderson considered the age of the shale interbedded on Canoas Creek between Eocene sandstone below and Miocene sandstone above as an integral part of the Eocene. Paleontologic proof was offered in their record of "*Orbitolites* sp. *a*"[1] from the same strata 9 miles southeast. The specimen they figured from there is undoubtedly *Orthophragmina clarki* Cushman, which was formally described from the Eocene.

The "upper member north of Coalinga" referred to by Arnold and Anderson is the one which F. M. Anderson had previously referred to—in other words, a shale situated above the three named Eocene members of his classification but still below the Miocene sandstones near Oil City.

No other authors appear to have given consideration to the age of the Kreyenhagen shales at the type locality on Canoas Creek. In company with Mr. E. G. Gaylord and Mr. James Dumble I have visited the locality and agree with the description given by Arnold

[1] *U. S. Geol. Surv. Bull. 396*, Pl. 2, Fig. 6; *Bull. 398*, Pl. 25, Fig. 6.

and Robert Anderson in all essentials. Good exposures are practically wanting there, and except in one instance weathering had so disintegrated the shales that no trace of organisms could be found, if indeed any were ever present. Near the center of the deposit, however, there is a slightly harder layer of thin, yellowish shale which weathers out in pieces almost a foot square. In several of these we found well-preserved *Pecten interradiatus* Gabb, a mollusk described from the Eocene near New Idria and apparently confined to rocks of that age. Between this fossil-bearing layer and the Miocene sandstones above there does not appear to be any indication of a break such as would be expected between Eocene and Oligocene strata.

Therefore, the only paleontologic evidence available places the Kreyenhagen shales at the type locality on Canoas Creek as well as the locality north of Coalinga mentioned in the original description definitely in the Eocene.

We may now give consideration to the formation north of Coalinga which has been the cause of much misapprehension in the past. A line drawn from northwest to southeast in the vicinity of the old camp known as Oil City crosses the following strata in ascending order:

1. Massive Cretaceous sandstones, the Panoche formation of Anderson and Pack[1]
2. Soft clay shale, massive, dark in color and with light-colored lenses of harder, laminated material; definitely Cretaceous in age; called "Moreno" by Anderson and Pack but not certainly the same as their Moreno at the type locality
3. Soft clay shale, massive in deposition, definitely Eocene in age; Foraminifera and mud-dwelling Mollusca abundant
4. Soft sands and sandstones with many characteristic Eocene Mollusca
5. Brown and yellow, thinly bedded siliceous shales containing large numbers of diatoms, radiolarians, sponges, fish remains, and a few Mollusca
6. Hard sandstones containing abundant fossils of definitely Lower Miocene age

We are here concerned chiefly with the last four of these formations (all above the Cretaceous) and may well consider them in ascending order.

[1] *U. S. Geol. Surv. Bull. 603* (1915), p. 39.

3. This brown to black, soft clay shale is slightly sandy in some parts and contains considerable carbonaceous material. Nodules of barite are frequently found. The contact with the Cretaceous shale below is very ill defined and probably cannot be traced far except by faunal content. The lower and older stratum contains ammonites and some characteristic Foraminifera. The upper shale contains an abundant fauna of Eocene Foraminifera, particularly near the top. From a sandy layer in this, F. M. Anderson derived the specimens he figured.[1] We have found a great many more, one of which is of especial significance, *Orthophragmina clarki*, because Arnold and Robert Anderson found this south of the type locality of the Kreyenhagen shales in strata supposed to be the exact equivalent. In addition to this we have found *Pecten interradiatus* in the clay shales, and it was found at the type locality of the Kreyenhagen shale. It therefore appears almost a certainty that the lowermost Eocene exposed in the vicinity of Oil City is the exact equivalent of the original Kreyenhagen of F. M. Anderson. His Avenal sandstone is missing, apparently overlapped. The Kreyenhagen here is roughly estimated at 1,500 feet thick and in addition to the fossils mentioned contains corals of definitely Eocene age and some fossil crabs. No trace of diatoms, radiolarians, or sponges (all siliceous organisms) was found.

4. Above this Eocene clay shale, the equivalent of the Kreyenhagen at the type locality on Canoas Creek, lies a sandy member, partially loose, partially consolidated into a friable stone. This contains abundant molluscan remains, the Eocene age of which is incontestable. There is no clear-cut unconformity between it and the underlying shale at the Oil City locality. The thickness of this sandy layer is probably 100 feet there. Possibly this is the member of the Eocene called by F. M. Anderson, Domijean sands, farther to the north where it is better developed. This member is entirely missing at the type locality of the Kreyenhagen shale on Canoas Creek.

5. Above this Eocene sandstone at the Oil City locality there is a deposit of shale so like that part of the Miocene known as Monterey shale that it was long considered to be of that age. The thickness of the layer is about 1,500 feet (a rough estimate), and there is no well-

[1] *Proc. Calif. Acad. Sci.*, Vol. 2, (3d series, 1905), No. 2, Pl. 13, Figs. 9–29.

marked unconformity between it and the Eocene sands below. Because of this fact, F. M. Anderson pointed out that it was structurally more closely related to the Eocene than to the Miocene where he had previously put it[1] and suggested that it might be Eocene or Oligocene. Arnold and Robert Anderson[2] treated it as Eocene but recognized the possibility of its being Oligocene. Robert Anderson and Pack[3] described the formation at length while tentatively placing it in the Oligocene.[4] They, unfortunately, correlated it with the Eocene shales on Canoas Creek which was named Kreyenhagen. Later writers have called it Oligocene without question and have continued the misappropriation of the name Kreyenhagen.[5]

6. The hard sandstone reef above this siliceous shale just referred to has been recognized as Lower Miocene, first Temblor and then Vaqueros, since it was first studied. It contains an abundant and unmistakable fauna. At the Oil City locality there is apparently a decided unconformity between it and the underlying siliceous shale. A similar unconformity has also been recorded elsewhere where a siliceous shale underlies a Lower Miocene sandstone reef, as, for instance, at Wagon Wheel Mountain.[6] It has generally been believed of late that this sandstone member occupies the extreme base of the Miocene series and that the underlying shales must be Oligocene. This opinion is based chiefly on the structural phases of the problem, although Clark[7] does list three mollusks, *Macrocallista pittsburgensis*, *Leda lincolnensis*, and *Fusinus (Exilia) lincolnensis*, from the underlying shales which he stated to be characteristic of the Oligocene. The last is figured[8] apparently from a

[1] *Ibid.*, Vol. 3 (4th series, 1908), pp. 15–16.

[2] *U. S. Geol. Surv. Bull. 398* (1910), p. 62.

[3] *U. S. Geol. Surv. Bull. 603* (1915), pp. 50, 74–78.

[4] Their description is as follows: "The term Kreyenhagen shale is used in the present report to designate a formation of probable Oligocene age comprising about 1,500 feet of diatomaceous shale which overlies the sandstone of the Tejon formation [Upper Eocene] north of Coalinga and which is believed to be the correlative of the Tertiary strata south of Coalinga described by F. M. Anderson as the Kreyenhagen shales" [p. 50].

[5] See Clark, *Univ. Calif. Pub. Geol.*, Vol. 11 (1918), p. 99.

[6] Arnold and Johnson, *U. S. Geol. Surv. Bull. 406* (1910), p. 41.

[7] *Univ. Calif. Pub. Geol.*, Vol. 11 (1918), p. 99.

[8] *Op. cit.*, Pl. 23, Fig. 10.

cast and shows some very decided differences from the type of the species described from Washington.[1] It would seem that these differences are sufficient in a cast to make identification questionable. The identity of *Macrocallista pittsburgensis* Dall from these beds is questioned by Clark himself on a later page of his publication.[2] This leaves only *Leda lincolnensis* Weaver as a positive basis of correlation of this supposed Oligocene shale with the Oligocene of Washington, and the author did not refer to it elsewhere. Mollusca in the siliceous shales are usually preserved as casts only. and if this *Leda* was such a specimen, it likewise might well be questioned as to specific identity. At any rate, species in the genus are not generally considered good horizon-markers.

Therefore it appears that the proof offered to date of the Oligocene age of this bed of siliceous shale overlying Eocene sands at the Oil City locality is entirely inadequate, and we are justified in questioning the identity of the age of it with so-called Oligocene strata of Washington or even with what Clark has called San Lorenzo of Mount Diablo. He furnished further evidence to justify this doubt in listing *Pecten peckhami* Gabb from the strata north of Coalinga,[3] but this species does not appear in any of his lists of Oligocene fossils from the Mount Diablo region and, furthermore, has not been listed from the Oligocene of Washington.

This Oil City shale bears a striking resemblance to Miocene shales elsewhere, and much of its fauna and flora is found in shales above the Lower Miocene reef. If numbers of species are of any value in correlation, then the evidence that the age is the same as what has been called Miocene elsewhere is almost overwhelming. There is also the possibility that the unconformity between the sandstone reef and the shale below is due in large part to warping and crushing of the shales after the whole was laid down. Even greater unconformities than that mentioned may be found between integral portions of the shale itself.

[1] Weaver, *Univ. Wash. Pub. Geol.*, Vol. 1 (1916), No. 1, pp. 51–52, Pl. 4, Figs. 49, 50.

[2] *Op. cit.*, p. 178.

[3] *Op. cit.*, p. 178.

SUMMARY

1. The Kreyenhagen shale at the type locality is Eocene in age. North of Coalinga its equivalent is Eocene and is overlaid by a sandy, Eocene member and underlaid by a Cretaceous clay shale.

2. The siliceous, diatomaceous shale above the Eocene sandstone north of Coalinga may be the equivalent in age of what is called Oligocene elsewhere, but the bulk of the evidence thus far seen indicates that it belongs to the Miocene period of deposition in California. If the oft-repeated statement is true that one of the major breaks in all geologic time comes between the Oligocene and Miocene, then the contents of the shales above and below this Lower Miocene reef should show very great differences, but they do not. We do not question the possibility that the lower part of this series, which may be conveniently called "an epoch of organic silica," may be shown to be the equivalent in time of the so-called Oligocene elsewhere, but until this is done it seems far more logical to continue to place it in the Miocene, to which it is intimately related, paleontologically and structurally.

3. The interbedded sandstones of the Miocene epoch in California are minor phases of an era when enormous thicknesses of strata, composed largely of siliceous skeletons of micro-organisms, were being laid down. These sandstones, being local in character and close to incoming streams, must necessarily vary in vertical position in the series, depending, as they did, upon climatic conditions of adjacent land areas. Therefore it does not seem strange that at the Oil City locality there is a deposit of 1,500 feet of shale beneath the lowermost Miocene sandstone member while on Canoas Creek the sandstones either overlap the shale or date from the beginning of Miocene time. In this region of instability, continuous deposition through so long a period as the Miocene without warping and resulting unconformities could hardly be expected.

GEOLOGY AND OIL RESOURCES OF TRINIDAD, BRITISH WEST INDIES

G. A. WARING AND C. G. CARLSON
Tulsa, Oklahoma

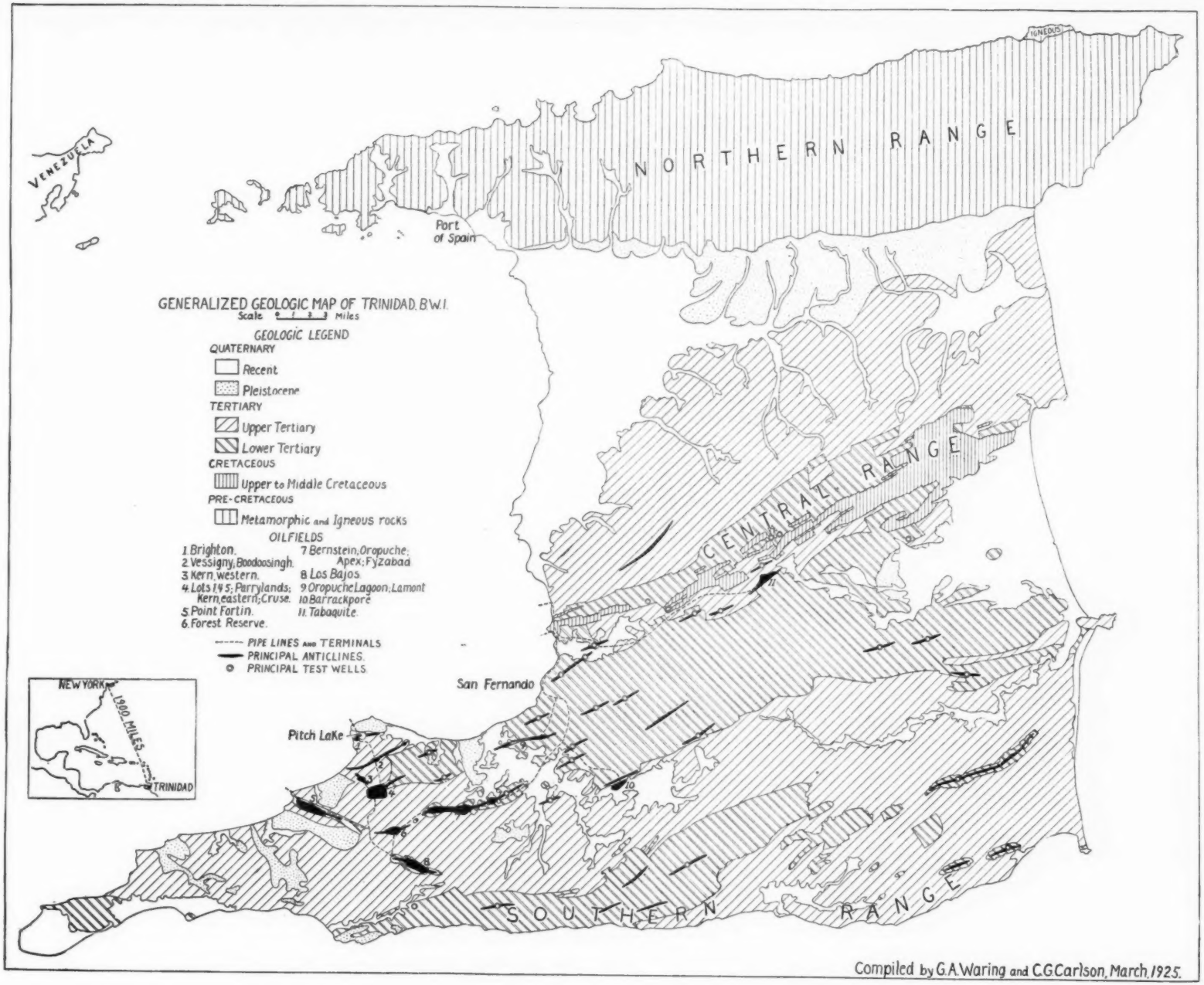
ABSTRACT

The island of Trinidad lies off the east coast of Venezuela, being separated from the mainland by a shallow gulf. It is about 50 miles long by 30 miles wide and divided into five zones by three nearly parallel east-west ranges. The Northern Range is of schists and altered limestones of Cretaceous or earlier age. The Central Range is of Tertiary deposits, including great thicknesses of clays. Oil is produced from anticlinal structures in the southern part of the island, at depths of 300–2,000 feet, chiefly from Miocene beds. The oil varies in gravity from 16°–41° Baumé, the present production being about 12,000 barrels daily, from eleven pools.

INTRODUCTION

Location.—Trinidad is the southernmost of the West Indian Islands, and lies off the east coast of Venezuela, being separated from the mainland by the shallow Gulf of Paria, into which flows part of the water of Orinoco River. It is 1,900 miles by steamer from New York and 700 miles east of the Maracaibo oil fields of Venezuela. The island is about 50 miles long from north to south, is 30 miles wide, and is divided into five topographic provinces by three east-west ranges, as shown in Plate 17.

Topography.—The Northern Range rises abruptly from the Caribbean Sea and attains a mean elevation of 1,500–2,000 feet, with a few peaks reaching 3,000 feet. Its steep flanks are scored by deep, narrow valleys. The Central and Southern ranges reach maximum elevations of only about 1,000 feet. The topography of the former is in part rolling, but in most of the Southern Range the slopes are steep, with cliffs along much of the south coast. The northern lowland zone is nearly flat, with detrital slopes rising gently to the flanks of the ranges on either side. The southern lowland zone consists largely of rolling lands. Both lowland areas rise only 200–300 feet above sea-level, the coastward portions of each constituting wide swamps and savannahs.


IGNEOUS
NORTHERN RANGE
VENEZUELA
Port of Spain
GENERALIZED GEOLOGIC MAP OF TRINIDAD, B.W.I.
Scale 0 1 2 3 Miles
GEOLOGIC LEGEND
QUATERNARY
Recent
Pleistocene
TERTIARY
Upper Tertiary
Lower Tertiary
CRETACEOUS
Upper to Middle Cretaceous
PRE-CRETACEOUS
Metamorphic and Igneous rocks
OILFIELDS
1. Brighton.
2. Vessigny, Boodoosingh.
3. Kern, western.
4. Lots 19 5; Parrylands; Kern, eastern; Cruse.
5. Point Fortin.
6. Forest Reserve.
7. Bernstein, Oropuche; Apex; Fyzabad
8. Los Bajos.
9. Oropuche Lagoon; Lamont
10. Barrackpore
11. Tabaquite.
PIPE LINES AND TERMINALS
PRINCIPAL ANTICLINES.
PRINCIPAL TEST WELLS.
CENTRAL RANGE
San Fernando
Pitch Lake
NEW YORK
1900 MILES
TRINIDAD
SOUTHERN RANGE
Compiled by G.A. Waring and C.G. Carlson, March, 1925.

About half the total area of the island is under cultivation, chiefly in cocoa, sugar cane, and coconuts. The remainder, except the swamp lands, is covered with dense, tropical forest

Geological investigations.—The earliest systematic geologic work was that of Wall and Sawkins,[1] in 1856–58, whose conclusions as to the stratigraphy have been found by later observers to be remarkably accurate. Numerous articles on the geology and paleontology were published by R J. L. Guppy[2] during his residence on the island from 1859 until his death in 1916. Government reports on the structure as related to the oil resources were prepared by E. H. Cunningham-Craig in 1905–7.[3] More recently, articles of special note have been published by Illing, Macready, and Milner.[4] Detailed study of the fossil molluscan fauna is being made by Professor G. D. Harris, and of the fossil flora by Dr. E. W. Berry; and Messrs. F. W. Penny and P. W. Jarvis have made extensive study of the fossil Foraminifera.

The present paper is based on the work of the writers during 1921–23 for the Trinidad Petroleum Development Company, Ltd. (subsidiary of the Whitehall Petroleum Corporation, Ltd.), who have kindly given permission for publication.

GEOLOGY

The oldest rocks exposed are those of the Northern Range. These consist of quartz-, mica-, and talc-schists, with minor deposits of grits, crystalline limestones, and carbonaceous schists, and one small area of basic igneous rock on the northeast coast. The whole series is tentatively considered to be of pre-Cretaceous or possibly Lower Cretaceous age. In the core of the Central Range there are grits and black shales with limestone lenses, all of Cretaceous age, but

[1] G. P. Wall and J. G. Sawkins, "Report on the Geology of Trinidad," *West Indian Survey*, Part 1. London, 1860.

[2] Most of Guppy's important contributions were published in the *Quarterly Journal of the Geological Society* or in the *Geological Magazine*. Others have been reprinted by G. D. Harris as Vol. 8, No. 35 (March, 1921), of *Bulletins of American Paleontology*.

[3] These have been published as *Council Papers of the Trinidad Government*.

[4] V. C. Illing, "The Oilfields of Trinidad," *Proc. Geol. Assoc.*, Vol. 27, 1916; G. A. Macready, "Petroleum Industry of Trinidad," *Trans. Amer. Inst. Min. and Met. Eng.*, Vol. 165 (1921), pp. 56–57; H. Milner, "Trinidad, a Review of Its Geology and Oil Resources," *Min. Mag.*, Vol. 25 (1921), pp. 139–48 and 205–13.

the greater part of the Central Range and all of the Southern Range and the lowlands between the two ranges are covered with Tertiary deposits. The Eocene and Oligocene periods are poorly represented by a few exposures of fossil-bearing calcareous sandstones and associated silts. The deposits are predominantly of Miocene silts, clays, and marls, foraminiferal throughout; with sandy beds in the upper portion of the series which are in part of estuarine and fresh-water deposits and contain thin beds of lignite and carbonaceous clay. The evidence obtained from fossils indicates that there may be marine and brackish-water Pliocene deposits beneath the swamp lands.

The major unconformities are believed to be: one separating the metamorphic rocks of the Northern Range from the Cretaceous of the Central Range; one between the Cretaceous and Eocene; and probably one between the Eocene and Oligocene, with several overlaps in the Miocene series of deposits.

STRUCTURE

The rocks of the Northern Range dip prevailingly to the south, but there are evidences of anticlinal and isoclinal folding which suggest that the range forms an anticlinorium. This seems to be profoundly faulted along its axial portion, with the northern part dropped below the Caribbean Sea.[1] Transverse valleys indicate the presence of cross-faults, with the blocks dropped successively lower to the west, the westernmost ones forming small islands which extend as a continuation of the Northern Range toward the mountains of the Venezuelan coast. Although the folding and faulting render it difficult to measure the thickness of the Northern Range rocks, it seems probable that 2,000–3,000 feet of metamorphosed sediments form this range.

Little is known of the structure in the northern lowland zone, as it is largely covered with wash from the mountains and by stream and swamp deposits, but the attitude of the late Tertiary beds where exposed in this lowland shows that their folding has been gentle.

[1] The writers are not in accord with Cunningham-Craig, and Macready, that there is a fault along the south base of the Northern Range.

The structure in the Central Range is characterized by cross-faults, and by close folds which pass into overturns and thrust faults. In the rolling lowlands south of the Central Range there is also much close folding and thrust faulting, but toward the middle part of the lowlands the folding becomes less intense and the central portion forms a wide, synclinal trough which extends across the island.

In the Southern Range the folding and faulting are again more intense, with the beds along most of the south coast dipping at angles of 60°–80°. Nearly all of the anticlines trend N. 60°–70° E., approximately parallel with the mountain ranges. The Miocene deposits are included in the intense folding.

The exposed thickness of Cretaceous rocks is about 500 feet, but the base of the series is not shown. The total thickness of Tertiary deposits is difficult of estimate because of the complex structure, but it is believed to have a maximum of 4,000 feet in the southeast, thickening westward to perhaps 7,000 feet.

OIL PRODUCTION

With the exception of limestone, which is used extensively for road metal and in small amounts burned for lime, the only deposits of economic importance are petroleum and asphalt. None of the lignite beds have been found of sufficiently good grade to be worked profitably.

In the southern part of the island there are numerous evidences of oil, such as oil-stained sands, mud volcanoes, and a few oil springs. No surface evidences of oil have been found north of the Central Range. All of the developed oil fields are within the synclinorium of the southern lowland zone, and all are on anticlinal structures, in some cases modified by faulting.

The commercial production of oil began in 1908, and except during the early part of the Great War and the year following the Armistice, has been on the increase, as shown in Figure 1. The production in 1924 of 4,284,000 barrels, or 11,700 barrels daily, came from about 300 wells in 11 fields, operated by 15 companies, as follows (Table I):

Of the total of approximately 900 wells drilled in the island to the close of 1924, only about 70 have been outside the producing

fields. The locations of the principal tests are indicated on the map (Fig. 1). In addition to the developed anticlines, there are several within the Southern Range which seem promising. The southeasternmost of these folds has been tested by several wells and found to

TABLE I

PRODUCING OIL FIELDS IN TRINIDAD

Fields	Companies	Approximate Daily Production in 1924
		Bbls.
Brighton	Trinidad Lake Petroleum Co., Ltd.	100
Vessigny	Trinidad Lake Petroleum Co., Ltd.	200
Boodoosingh	Kern (Trinidad) Oilfields, Ltd.	
Kern, western	Kern (Trinidad) Oilfields, Ltd.	300
Lots 1, 4, and 5	Petroleum Development Co., Ltd.	2,500
Parrylands	United British Oilfields of Trinidad, Ltd.	
Kern, eastern	Kern (Trinidad) Oilfields, Ltd.	
Cruse	Trinidad Central Oilfields, Ltd.	
Point Fortin	United British Oilfields of Trinidad, Ltd.	300
Forest Reserve	Trinidad Leaseholds, Ltd.	3,000
Bernstein	Trinidad Leaseholds, Ltd.	4,000
Oropuche	General Petroleum Co. of Trinidad, Ltd.	
Apex	Apex (Trinidad) Oilfields, Ltd.	
Fyzabad	Petroleum Options, Ltd.	
Fyzabad	Trinidad Freeholds, Ltd.	
Fyzabad	Trinidad Friendship Petroleum Co., Ltd.	
Fyzabad	Trinidad Oil Producing and Refining Co., Ltd.	
Los Bajos	United British West Indies Petroleum Syndicate, Ltd.	200
Oropuche Lagoon	British Controlled Oilfields, Ltd.	300
Lamont	Trinidad Petroleum Development Co., Ltd.	
Barrackpore	Trinidad Leaseholds, Ltd.	500
Tabaquite	Trinidad Central Oilfields, Ltd.	300
Total		11,700

be productive, but, on account of its remoteness, it has not yet been commercially developed. Because of the heavy expenses of road-making and other preliminary work in the forested areas, there has been little testing of other relatively inaccessible structures.

Three principal oil-bearing formations are recognized, consisting,

respectively, of sands in the Oligocene (and possibly Eocene) deposits; sands at several horizons in the lower, more clayey portion

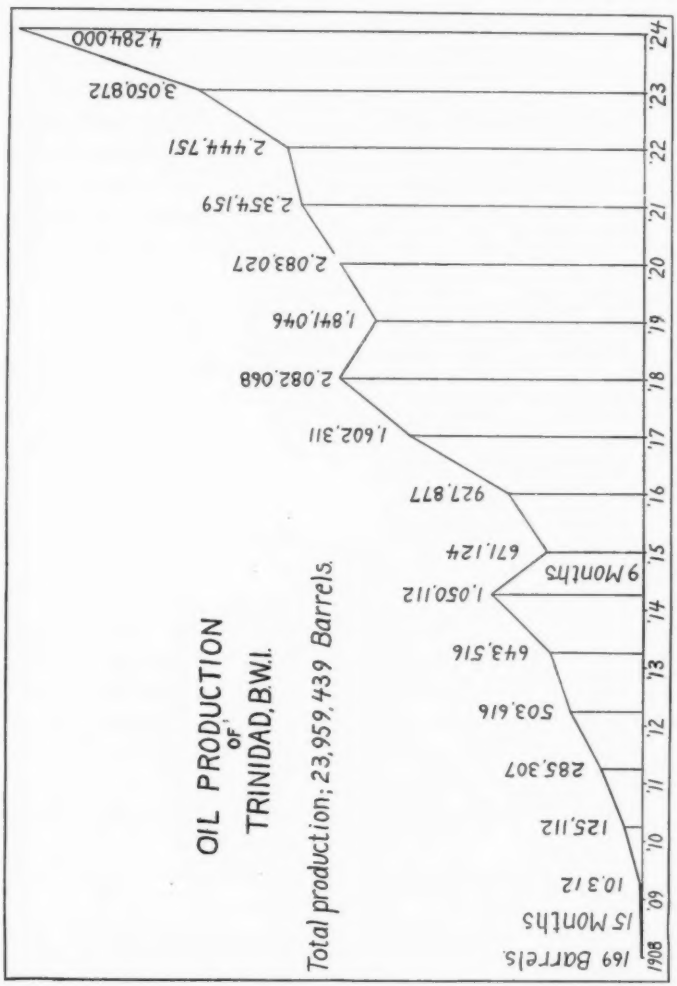


FIG. 1

of the Miocene beds; and sands in the upper, coarser-grained deposits of the Miocene. Oil is obtained in the northernmost field at

depths of from 1,200 to 1,400 feet, from sands in the Oligocene or Eocene deposits. The same grade of oil (41° Baumé), is also obtained in this field at from 300 to 500 feet, presumably from Miocene sands unconformably overlying the older beds. More than 90 per cent of the island's production comes from the fields of the southwest, where oil is obtained chiefly from the deeper horizons of the Miocene, at depths of from 600 to 2,000 feet. The gravity ranges from 15° to 28° Baumé. The oil is obtained from zones of interbedded sands and clays or shales rather than from distinct sands separated by shale members. The following analyses (Table II) show the general character of the oils:

TABLE II

ANALYSES OF OILS FROM TRINIDAD, B.W.I.
(J. McConnell Sanders, analyst, 1921–23)

Constituents	Brighton	Lot Four	Forest Reserve	Barrackpore	Lamont	Tabaquite
	Gravity Baumé					
	15°	16.5°	21.5°	23°	28°	41°
	Specific Gravity					
	0.966	0.956	0.925	0.915	0.886	0.818
	%	%	%	%	%	%
Gasoline	.....	0.6	.....	.....	18.3	.....
Naphtha	5.6	.....	1.7	9.2	.....	21.2
Kerosene	22.8	26.2	39.2	43.2	29.5	50.2
Gas oil	.....	8.1	.....	.....	.....	.....
Lubricants	12.8	19.4	33.9	39.6	25.9	28.4
Asphalt	56.7	45.9	24.2	6.0	26.3	0.1
Water and loss	2.1	.....	1.0	2.0	.....	0.1
Total	100.0	100.2	100.0	100.0	100.0	100.0

Before detailed areal and subsurface studies had been made in the oil-producing districts, it was thought by some that the oil was related in origin to the lignites of the Upper Tertiary formations. Nearly all of these lignites, however, are high above the oil sands. The most probable source beds for the oil are the foraminiferal clays and marls, within or not far above which the productive sands are encountered.

Some of the wells come in at the rate of several thousand barrels daily, but they often sand up after flowing for a few hours or days. Although they come in under heavy pressure, relatively little gas is produced after the initial flows, and none of the fields has sufficient gas for its own fuel needs. The heavy, initial gas pressure and fineness of the sands have caused much difficulty in bringing wells in under control. In some fields it has been the practice to allow the wells to flow through perforated casing until the gas pressure has been relieved, when the flow is choked down to prevent further caving and bridging. Screens have been successfully used in only one field, where the producing sand is so fine that 90 per cent passes a 200-mesh screen. Because of the unconsolidated nature of the formations the wells are not shot, and for the same reason the rotary system of drilling is chiefly used, except for the shallowest oil sands. In some fields, salt-water sands are interbedded with the oil sands, but definite edge water has not been recognized. The lenticular nature of the sands has led to unequal spacing of wells in some of the fields, but the present tendency is toward equal spacing, at intervals of 300 feet.

Many of the wells have been short lived, as the loose sands have been rapidly exhausted, but a number are still good producers after eight years or more. One of the largest wells yielded a total of 470,000 barrels before exhaustion; and another, which had produced 315,000 barrels during its first two years, was at the end of that time pumping 230 barrels daily.

The oil is piped to four terminals on the west coast, and much of it is run through topping plants before shipment. Trinidad and adjacent places are supplied with motor spirit, but much of the kerosene used is imported from the United States. The greater part of the oil is taken by the British Admiralty and other British interests, but during the past few years considerable has been sent to New York. Although nearly all of the producing companies are under British control, within the past two or three years the restrictions imposed during the war period on alien companies have been relaxed.

By an ordinance effective January 17, 1902, the Crown retained the subsurface rights to all lands not alienated before that date, so that there are three classes of lands: (1) those of which surface and subsurface rights belong to the Crown; (2) new-title, alienated lands

of which the owner has title only to the surface; and (3) old-title lands of which the owner has both surface and subsurface rights. Practically all of the first-named class is under license to oil companies, and also most of the second class, though operations on these lands are handicapped by the necessity to arrange with the surface owner for entry on the property and compensation for injury to cultivation. Much of the old-title land within the well-recognized anticlinal areas has been acquired for oil exploitation, but the cost of such lands has been high, partly because of speculation and partly because of the preference of the owners to sell outright rather than lease, on the basis that oil operations are very injurious to agriculture, especially to cocoa estates.

ASPHALT

In addition to oil, Trinidad is noted for its asphalt production from Pitch Lake, adjacent to the Brighton oil field. The lake has a nearly circular outline, $\frac{1}{3}$ mile in diameter. Nearly five million long tons of asphalt have been removed from it since the beginning of extraction in 1867, and the lake-level has thereby been lowered about 16 feet. Some of the asphalt is shipped in the crude state, but most of it is refined by melting to remove the contained water. The approximate composition of the crude material is: bitumen, 40 per cent; clay, 30 per cent; water, 30 per cent. The refined product consists of 60 per cent bitumen and 40 per cent clay. The intimate admixture of clay with the bitumen is largely responsible for the high quality of the material for street paving.

FUTURE POSSIBILITIES

Although Trinidad may never become a much more important factor in oil production than it is at present, it is likely to be a fairly steady producer for many years; and it seems to the writers that the possibility for new pools lies chiefly in the anticlines of the southeast and in some block-faulted areas in the south and southwest.

CALICHE AND PSEUDO-ANTICLINES[1]

W. ARMSTRONG PRICE
Houston, Texas

ABSTRACT

Observations in central Tamaulipas, Mexico, indicate that pseudo-anticlines may be formed by deposition of caliche (lime carbonate) at shallow depths below the surface. The surface rocks are accordingly disturbed, and dips up to 17° have been observed on strata which are apparently in place. The maximum vertical uplift of these caliche-formed pseudo-anticlines is about 15 feet; their length along the axis of the "buckle" may be as much as 2,000 feet. Beneath the pseudo-anticline the strata are essentially horizontal.

Caliche deposition is seen to be a factor in the process of weathering in semi-arid regions: On the one hand, it moves and disrupts rock beds and aids in the penetration of plant roots at the outcrop; on the other hand, it retards weathering and erosion by re-cementing the rock fragments.

The coastal plain of the Gulf of Mexico is noted among field geologists as a region where there is a minimum number of surface outcrops on which determinations of dip may be made. The geologist has to depend, in this region, largely on areal relationships and subsurface data from which to deduce the structure, both regional and detailed.

The scarcity or absence of consolidated strata over large areas is matched, here, by the unreliability for detailed structural mapping of the larger number of the few hard beds which are exposed. Cross-bedding and the ready weathering of bedding planes in unconsolidated or soluble strata, combined with slumping and creep in clay shales, invalidate most outcrops as dependable structural data.

In the west-central portion of the Gulf Coastal plain, in southwest Texas and in Mexico (Fig. 1), a thick and widespread growth of tropical brush, or "monte," adds an additional hazard to the search for good dips, not only in impeding travel, retaining the soil and concealing outcrops, but also in disrupting and tilting joint slabs of the harder rocks at the outcrop beneath the soil. When erosion removes the soil covering, the first portion of the outcrop exposed to

[1] Published through the courtesy of H. L. Hollis, Consulting Mining Engineer, Chicago, Illinois.

view is consequently apt to be lying in a disturbed position. This is particularly true of flagstone beds in shale.

EXAMPLE OF JUMBLED FLAGSTONE OUTCROPS IN MEXICO

At a locality in northern Vera Cruz,[1] between Ozuluama and Tampico, level Tertiary flagstones were seen in a dry water well, while all the abundant flagstone slabs appearing through the soil on low mounds surrounding the well were steeply inclined. Some of these might have been taken as indicating the direction of true dip if the exposures in the well had not been seen. Examples could be multiplied.

FIG. 1

LARGE-SCALE DISTURBANCE OF FLAGSTONE BEDS BY CALICHE

In a large area of outcropping, thin-bedded limestones and sandstones (Fig. 2*a*) in Mexico, extensive exposures of flagstone surfaces, from which the soil had been washed and which were in many cases not visibly penetrated by roots of the heavier plants of the "monte," appeared to offer true dips. These exposures might have been accepted as "in place" but for a succession of peculiar minor folds or buckles (Fig. 2*b*) in the flagstone beds which, on the basis of considerable detailed study, appeared to have had a recent origin.

The assumption was first made that, since the buckles[2] occur on

[1] The hacienda town of Quebrache.

[2] Instead of "buckle," implying horizontal pressure, a better term for these small folds would be *flexure*.

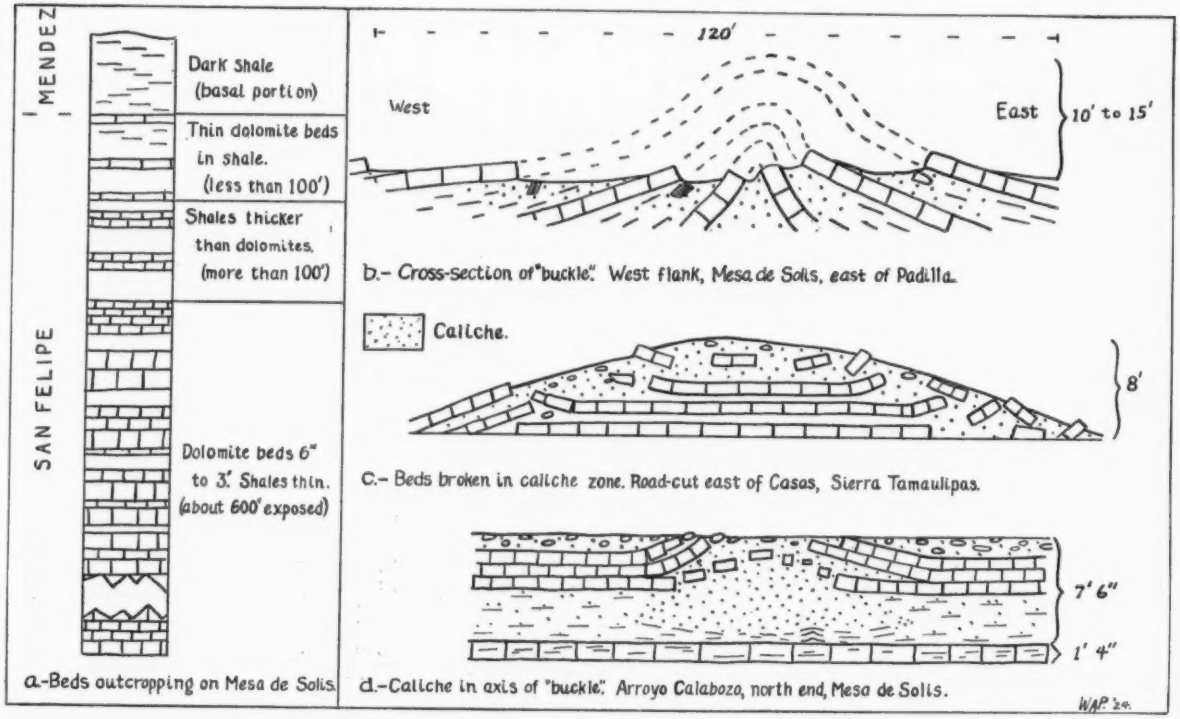

MENDEZ
SAN FELIPE
Dark Shale
(basal portion)
Thin dolomite beds
in shale.
(less than 100')
Shales thicker
than dolomites.
(more than 100')
Dolomite beds 6"
to 3'. Shales thin.
(about 600' exposed)
a.-Beds outcropping on Mesa de Solis.
120'
West
East
10' to 15'
b.- Cross-section of "buckle". West flank, Mesa de Solis, east of Padilla.
Caliche.
8'
c.- Beds broken in caliche zone. Road-cut east of Casas, Sierra Tamaulipas.
7' 6"
1' 4"
d.-Caliche in axis of "buckle". Arroyo Calabozo, north end, Mesa de Solis.
W.A.P. '24.

FIG. 2

a large anticline many miles in length, they might have been formed during the uplifting of this arch, and represent on a small scale the development of the component folds on a geanticline. Their presence in a competent stratum, as well as in weak beds, combined with other considerations to be described, led to the abandonment of this assumption.

The final conclusion, that the minor folds were entirely superficial and recent in origin and to be classed with other disturbances of strata accompanying the process of weathering, was reached only after a thorough search had been made for deeply eroded exposures (Fig. 2*c*, *d*). The agent of this disturbance, caliche,[1] is a widely known surface deposit of tropical and semiarid regions. Its rôle in falsifying apparently good "dips" and in forming pseudo-anticlines has not been generally emphasized.

MESA DE SOLIS

The pseudo-anticlines were seen on the Mesa de Solis in Mexico. This mesa lies between Padilla and Jimenez in the state of Tamaulipas (Fig. 1), and east of Victoria, the capital of the state.

The Mesa de Solis, as the term is here used, is the low, middle portion of the central range of mountains of Tamaulipas and lies between groups of sierra at the ends of the range. It is 60 miles long, 8–10 miles wide, and rises to 500 feet above the plain in the area which was mapped in detail.[2] It is a bare, rocky ridge, sloping gradually on both sides in a series of broad terraces held up by heavy dolomites or courses of dolomites from which the interbedded shales have been eroded. South of its center, which is trenched by Soto la Marina River in a steep-sided, V-shaped canyon, the mesa is rolling

[1] The word *caliche* has had a variety of uses in the Americas; in Mexico and the United States its chief use is to designate superficial deposits of gravel, sand, or desert débris cemented by porous calcium carbonate; also the calcium carbonate itself. Also, in Mexico and Texas, chiefly in reference to a certain phase of the Reynosa formation of Pliocene (?) age, for a compact limestone. The variety here described is a porous calcium carbonate. The use of the word *caliche* to designate crude sodium nitrate (Chile) is closely related, genetically, to its use in Mexico, since the nitrate "caliche" is a desert deposit formed by evaporation. An occasional use of the term in Mexico for feldspar or white clay has been noted by writers. A. H. Fay, *U. S. Bur. Mines, Bull. 95*, p. 125; F. W. Clarke, *U. S. Geol. Survey Bull. 770*, pp. 255, 256.

[2] Four reconnaissance trips and a detailed traverse were made across the mesa from west to east. The length of the mesa from north to south covered by these traverses was 45 miles. About 30 square miles of mesa were covered in more or less detail.

and is cut by winding, lateral arroyos. The northern portion is smooth topped and cut by a few shallow ravines whose sides are blanketed with loose rock. The mesa is covered with a fairly dense growth of "monte" interspersed with bare areas which are developed chiefly along the few roads which cross it. It bears a scanty soil.

The Mesa de Solis is formed by 600 feet or more of dolomitic limestone and sandstone with intercalated calcareous shales of the San Felipe formation of the Cretaceous lifted in an anticlinal fold from which the overlying Mendez shale of the surrounding plains has been eroded.

The central portion of the mesa, along the axis of the main anticline, is composed of the lower, heavier-bedded, portions of the San Felipe. The dolomite weathers into beds up to 3 feet or slightly more in thickness. The flanks are composed of the upper and thinner-bedded portion of the formation (Fig. 2*a*) in which shale predominates over dolomite.

THE PSEUDO-ANTICLINES

In mapping this area[1] many dip determinations were made on exposures of flagstone surfaces from 20 to 300 feet or more in length, and from a few inches to 100 feet or more in width. Dips varying from 0° to 17° were measured.

Crossing many of these exposed surfaces, anticlinal folds or buckles were seen, with a few feet of vertical uplift (maximum observed not over 15 feet) and as long as 2,000 feet (Fig. 2*b*). The axes of the buckles run roughly parallel to the trend of the mesa and seem to follow joint planes. Where the buckles are broken down and eroded at the axis, lines of more abundant vegetation, often including only smaller brush, grow along the axes.

CALICHE ON THE MESA

The roots of the plants which grow along these axes are imbedded in caliche, which has impregnated the shales and formed in the joint cracks and often appears as a ridge of grayish-white, porous rock supporting a hedgelike plant growth.

Caliche is also abundantly developed over the surface of the mesa in beds of shale and, over large areas, conceals all outcrops. In the

[1] Mr. R. E. Lee Collins assisted the writer in the study of this area.

caliche are imbedded blocks and slabs of dolomite and masses of shale.

The occurrence of caliche along the axes of these minor folds led to a search for exposures of cross-sections of the buckles which would show them more deeply eroded than they could be seen on the comparatively even surface of the mesa.

LEVEL STRATA BENEATH STEEP DIPS

In a long, winding canyon heading in the mesa and crossing its axis, several bare cliffs show level-lying or slightly inclined, heavy-bedded, dolomitic sandstones. Exposures of 15–120 feet of strata were found. The steepest dip measured in the canyon walls was 3°. No caliche was seen in these cliff exposures. Dips measured in the canyon floor, where caliche has developed, were uniformly several degrees steeper than those of the walls.

Along a road[1] running near and parallel to this canyon, all observed surface outcrops were steeply inclined and showed dips quite conflicting in arrangement. In the walls of 8- to 10-foot cuts on this road, between La Gruya and Soledad, level beds were seen to be disturbed at their outcrops in the caliche-bearing zone. The disturbance of the beds has extended only as deeply as has the development of caliche (Fig. 2*c*).

An open well at the abandoned site of Soledad ranch showed in its walls 12 feet of caliche above 3 feet of horizontal dolomitic sandstone.

CROSS-SECTION OF A PSEUDO-ANTICLINE

In the head of a short branch of the Arroyo Calabozo at the northern end of the Mesa de Solis, a typical anticlinal buckle was seen in cross-section (Fig. 2*d*). The exposure shows a 9-foot section of dolomitic limestone and calcareous shale, the basal limestone lying horizontal or very nearly so. A bed of calcareous shale above it has been impregnated by caliche beneath the axis of the buckle. All trace of the shale bedding has been obliterated beneath the axis except in a thickness of a few inches at the base of the unit, where crumpling of the shale was noted. Lying above this shale is a group of thin-

[1] Highway between Casas, Abasolo and Soto la Marina. Outcrops described are on the mesa between Casas and Soledad.

bedded limestones, 2 feet and 9 inches in thickness, which is abruptly arched and partly broken into separate joint blocks immediately above the greatest development of caliche in the shale. It is the arching of this limestone which defines the buckle which was traced along the surface of the mesa to this arroyo. Caliche fills the spaces between the beds and surrounds the disjointed and separated parts of the upper limestone. The subsoil is composed of caliche and dolomitic rubble. No soil is present.

The amount of the vertical uplift in this buckle is 3 feet and 6 inches, and the vertical expansion in the shale with the development of caliche has amounted to 65 per cent of the original thickness of the shale bed. The fold is entirely superficial.

CALICHE AS THE CAUSE OF THE BUCKLING

These exposures establish the adequacy of caliche impregnation as a cause of the widespread disturbance of surface beds seen on the Mesa de Solis. It is believed that the disturbing action of plant roots in uplifting the flagstones is here insignificant in comparison to that caused by the growth of caliche, but that plant roots probably assist in opening joint cracks for the penetration of surface waters and for a consequent increase in the development of caliche.[1]

THE MEASUREMENT OF DIP ANGLES ON THE MESA

In consequence of this disturbance of outcrops, trustworthy dips can be measured in the area only in exposures reaching at least 8 feet below the general ground surface. A few broad exposures of flagstone groups were found in which no buckling was evident and on which the dips measured coincided with the estimated dip of the anticline, as determined from areal outcrop relationships.

Detailed mapping indicated that the longer exposures of super-

[1] In the absence of more than a scanty soil over large areas of the mesa, plant growth along the axes of the caliche-filled buckles is, in some cases, denser than on adjacent surfaces of bare flagstones. The plant roots easily penetrate the caliche, which softens when wet, and find there abundant lime and, perhaps, water. The development of the caliche and the growth of the plants are probably contemporaneous. A native rancher claims that he has successfully located water wells on these lines of thick vegetation. The scarcity of wells on the mesa did not permit the verification of this claim. There seems to be no reason, a priori, why these superficial features should materially affect the position of ground water.

ficial beds, and the longer and usually the steeper of such exposures on the buckles, in general, had components parallel with the estimated dip of the main anticline as the same point, as inferred from areal relationships and, in some cases, from trustworthy exposures. The actual dips from which such components were determined were steeper than the probable true dips.

CALICHE AND THE DISTURBANCE OF OUTCROPS IN SEMIARID REGIONS

The lithology and topography of the Mesa de Solis has afforded an exceptional opportunity in this region for the development of caliche between strata. It is probable, however, that the disturbance of surface beds which is fairly common in other parts of Mexico where thin-bedded rocks alternate with shale or weaker beds may be caused in part by the action of caliche, where this is present. It is also probable that similar disturbance will be found to be general in semiarid regions where abundant sources of soluble compounds suitable for the formation of caliche are at hand, and where the structure and lithology of the rocks permit the ready entry and circulation of surface and ground waters at shallow depths. In outcrops of heavy-bedded strata the disturbance will be less or absent, depending chiefly upon the presence and the distribution of intercalated shale.

The abundant development of caliche may prevent or seriously interfere with detailed structural mapping over large areas or necessitate the excavation of prospect pits, thus materially increasing the cost of field work.

SUMMARY AND CONCLUSIONS

1. On the Mesa de Solis in central Tamaulipas, Mexico, caliche impregnates shale strata and the bedding and joint planes of limestones and sandstones to depths of 10–12 feet or more, disrupting and lifting the beds.

2. Where this has occurred, most surface outcrops are rendered untrustworthy for dip determinations although they may appear to be firmly "in place" to one unfamiliar with this type of disturbance. True dip determinations are to be sought in fresh exposures below the zone of caliche impregnation.

3. The impregnation of caliche along dominant joint planes has formed minor pseudo-anticlines of shallow depth.

4. Similar disturbances of surface beds may be expected in semiarid regions where calcium carbonate and other soluble compounds are abundant in surface and ground waters and where the structure of the rocks permits the ready entry and circulation of these waters.

5. The growth of caliche takes a prominent part in the process of weathering in certain areas of semiarid lands. Its effect is twofold: On the one hand, it moves and disrupts rock beds at shallow depths, facilitating the entry of plant roots; on the other hand, it cements the broken rock fragments, retarding erosion.

GEOLOGICAL NOTES

COLOR CHART OF THE COMMITTEE ON SEDIMENTATION OF THE NATIONAL RESEARCH COUNCIL

Every geologist who has tried to describe the colors of rocks in the field has probably been dissatisfied with his results. The descriptions usually mean little to him when he reads over his notes in the office, and except when he is dealing with only a few groups of rocks very distinct from one another in color his descriptions do not help him much in correlating or comparing different exposures that he has seen. This has been due partly to his not having before him standard colors with which comparison could be made; partly to his not knowing how to define colors. But even with understanding of the three simple factors which, it is generally agreed, are necessary and adequate for describing any color, few could hope to have the perfect color memory that would enable them to place any color they see without having standards before them for comparison. Adequate description of colors will be a help not only in comparison and correlation but ultimately also in interpreting the origin of sedimentary rocks. It seems likely, for instance, that if certain sedimentary rocks were described, not merely as red but as a particular red, a differentiation of red beds into those formed under humid and those formed under arid continental conditions would soon result. The far-reaching importance of such a differentiation is obvious.

To meet this situation a subcommittee of the Committee on Sedimentation of the National Research Council is preparing a printed set of about ninety-six colors on two 5×8-inch sheets of paper, to be carried about in the field geologists' notebook. It is not, of course, supposed that this small number of colors will match every color that the geologist will encounter in sedimentary rocks, but the attempt has been made to have the range of colors cover about the range of what he will find. The colors will be arranged, numbered, and lettered to correspond with Ridgway's *Color Standards & Nomenclature* (1,115 colors; for sale by A. Hoen & Co., Chester, Chase and Biddle streets, Baltimore, Md.; $12.00 plus postage; weight 2 lb.) from which the colors for reproduction on this chart have been selected. Each chart will be accompanied by a brief explanation of

the three factors which determine any color and the consequent method of interpolating between the colors on the chart. The chart is intended only as a condensed, compact aid in color description in the field. In the office, for more exact identification and in order to train color perception, the use of Ridgway's fuller set of colors is urged.

On account of the difficulties inherent in the exact reproduction of colors it is not certain that a satisfactory set can be prepared. Unless these difficulties are overcome to the satisfaction of the members of the subcommittee, and the experts of the Bureau of Standards who have generously been giving them the benefit of their experience, no copies will be distributed.

As the printing of an edition of the chart requires a considerable investment, and the Committee of the National Research Council has no money to meet this, it will be necessary to procure, in advance, enough orders to insure the success of the enterprise. Therefore, all who consider the undertaking worth while are urged to send in an order; but as success is uncertain *do not send money with your order*. Prices will be raised after publication. The advance prices are: one copy, $0.60; ten copies, $5.50; one hundred copies, $50.00.

Please make your order as large as possible. In doing so it will, the Committee believes, be proper to figure that on account of soiling and of inevitable fading of some colors during use a set will not, on the average, last a man through a field season of more than three or four months. The colors should not fade if protected from light.

Send orders to Marcus I. Goldman, United States Geological Survey, Washington, D.C.

The Subcommittee on Color Chart:
H. E. MERWIN
MARCUS I. GOLDMAN, *Chairman*

GEOLOGIC STRUCTURE OF THE DAKOTA SANDSTONE IN WESTERN KANSAS

Prospectors for new oil and gas pools are diligently at work in many localities in western Kansas. By their effort the Russell oil field, in northwestern Russell County was discovered late in the fall of 1923, and is now producing more than 2,000 barrels of high-grade oil a day, and many wells are drilling in the field. Encouraging shows of oil or gas have been reported in wells drilled in no less than eighteen counties. Oil has been produced a few miles north of Hutchinson, gas has been found, the well being capped at present, in a well at Liberal near the southwest corner of the state, and several wells produce gas south of Wray, Colorado, within 5 miles of the west boundary of Kansas. Two

wells in the western part of the state are below a depth of 5,000 feet, one in Hamilton County recently abandoned at 5,488 feet, and one in Clark County more than a mile deep.

Many of the wells of western Kansas have been drilled subsequent to the compilation by N. H. Darton[1] of the Geological Survey of a preliminary map of the Central Great Plains showing the structure of the Dakota sandstone, and these wells have made available additional structural data. The writer as a representative of the State Geological Survey of Kansas and the U. S. Geological Survey, which have co-operated in this study, spent the latter part of October and the first two weeks in November, 1924, collecting recently available well records. Every county was visited and drilled wells were located and their elevations determined by aneroid in much of the area, and by location on the topographic sheets of the U. S. Geological Survey in the area that has been mapped topographically. All outcrops of known key beds in the Cretaceous rocks that were seen in the course of the route were sketched and elevations determined in like manner to that of the wells. Reconnaissance structural data that were secured earlier in the year in Russell County by W. W. Rubey and the writer, and in Ellis and Hamilton counties by the writer, are incorporated in the regional map. Information on file by oil companies operating in the region was used wherever available. The records of the Keys Petroleum Company of Wakeeney were of particular value and the writer is glad of this opportunity to acknowledge the courtesies shown by this company and others and by many individuals, too numerous to mention. It is regrettable that sufficient time to get records of all water wells was not available and that much other work which should be done cannot be undertaken because of lack of state funds. Consequently the structural features as shown can be modified somewhat by existing information from deep water wells, but it is believed that a sufficiently accurate regional picture of the structural conditions of western Kansas is shown to justify its publication although much improvement is no doubt possible.

The rocks exposed in that part of western Kansas shown in Figure 1 have at their base the Dakota sandstone, a formation about 300 feet thick, consisting of sandstone, sandy shale, and clay shale. It crops out in a broad band extending northeastward from Edwards and Stafford counties to Washington County. Overlying the Dakota sandstone, and with outcrops paralleling it on the west, are the Graneros shale, which consists of dark gray to black clay shale 35–40 feet thick in the eastern part and 60 feet thick in the southwest part of the area; the Greenhorn limestone, composed of alternately bedded thin limestone and limy shale having a thickness of 100 feet in the eastern part and 130 feet in the southwestern part; the Carlile shale, consisting of an upper division of noncalcareous dark gray shale with a sandy unit at the top, and a lower division of calcareous shales alternating with thin limestone, ranging in thickness between 300 feet in the eastern part and 250 feet in the southwest; and the Niobrara

[1] N. H. Darton, "The Structure of Parts of the Central Great Plains," *U. S. Geol. Surv. Bull. 691-A*, 1918.

formation, which consists of 700 feet more or less of chalk beds and chalky shale, the basal 60 feet being distinguishable from the remainder by its superior hardness and small content of shale. An unknown thickness of the gray Pierre shale occupies the extreme northwestern part of the state. Overlapping the eroded edges of the foregoing formations, from the Pierre shale to the Dakota sandstone, is a series of sand, gravel, and clay of late Tertiary age that occupies the surface

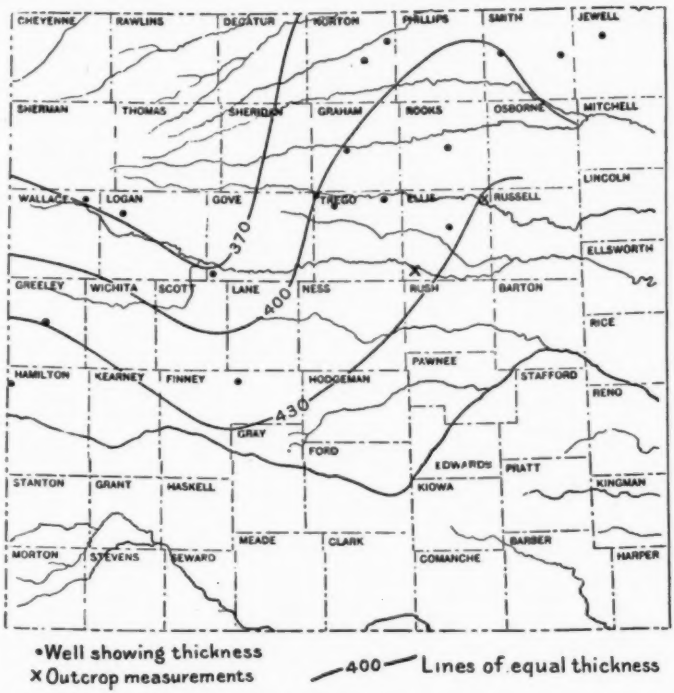


FIG. 1.—Sketch map of western Kansas showing combined thickness of Carlile shale, Greenhorn limestone, and Graneros shale.

of the greater part of the western half of the area and extends far to the eastward on the high drainage divides.

In the logs of wells drilled in the region the Pierre shale is not readily distinguishable from the Niobrara formation. The basal member of the Niobrara, which is, except for the Dakota sandstone, the best marker horizon in the logs of wells of the region, is nearly always logged as white limestone, above the several hundred feet of blue or black shale comprising the Carlile shale, the Greenhorn limestone and the Graneros shale. A sandstone at the top of the Carlile

is present in the greater part of the area. This shale unit (the Carlile, Greenhorn, and Graneros formations) thickens southeastward from the northwest part of the state. Figure 1 shows the approximate thickness of this unit in various parts of the region. The Dakota sandstone is the best marker in the stratigraphic section for a regional study, its top being logged as sandstone, sandy shale, and in some wells as red rock.

Below the Dakota are 100–200 feet of dark shale and light-colored sandstone of Comanche age that probably does not extend throughout the area, but

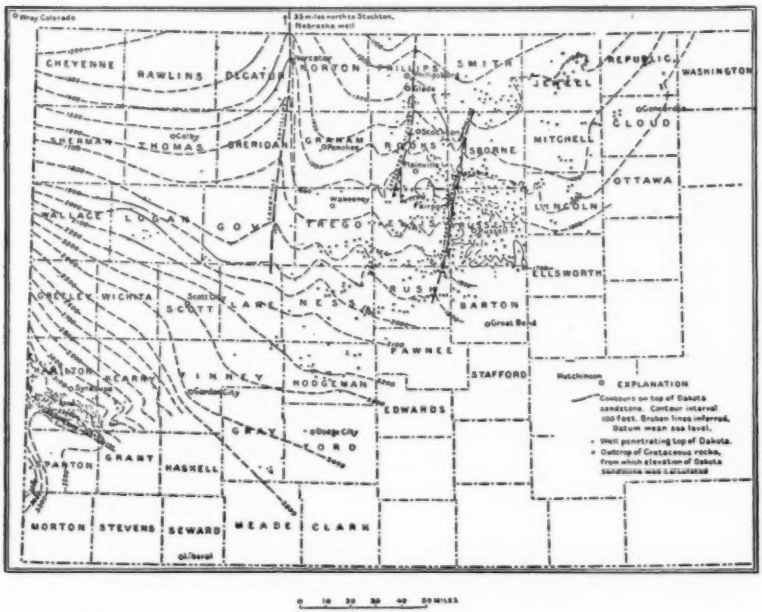


FIG. 2.—Reconnaissance map of western Kansas showing structure of the Dakota sandstone.

is present at least in the southern part of the region; a series of red beds largely of Permian age that ranges from less than 1,000 to more than 2,000 feet thick; and Pennsylvanian limestones and shales with a maximum thickness of more than 2,000 feet.

STRUCTURE

The most pronounced feature shown on the structure map (Fig. 2) as well as on Darton's map of 1918, is the Cambridge anticline, the axis of which trends northward through the eastern edge of Decatur County into Nebraska. The structure contours in Decatur County, western Norton and Graham counties

are based on a number of control points, but the southern extension of the nose through southern Sheridan and Gove counties is largely conjectural. Because of its greater size as compared with the other folds in Kansas it offers an attractive region for prospecting and should be thoroughly tested. A well is now being drilled near Norcatur on the crest of the fold.

A rather pronounced and extensive series of structural "highs" extends from northwestern Ellis County north-northeastward across Rooks County, passing a few miles west of Stockton and thence into Phillips County near Phillipsburg. It is possible that the nose crossing the southeast corner of Trego County is the southward continuation of the Stockton fold, or one *en echelon* to it. A well located south of Glade in Phillips County, another north of Stockton, and one southwest of Plainville in Rooks County, are being drilled on this regional high. The Glade well has been reported shut down at a shallow depth for several months. Inasmuch as it appears to be admirably located structurally, it is hoped that it will be continued.

The Fairport-Natoma anticline, which is most prominent near the Russell oil field, extends north-northeastward from eastern Rush County into northern Osborne County.

In the southwest part of the area the Syracuse anticline in Hamilton County is the most pronounced feature and is shown here much as presented by Darton's map, although some changes have been made. A well located on the Syracuse anticline was drilled to 5,488 feet but encountered no encouraging shows of oil or gas. The slight bending of the contours toward Scott City is based on a log of a water well given from memory, as a written record of the well could not be found. The position of the contours in this region is consequently subject to change.

N. W. Bass

CONCERNING THE ACCUMULATION OF OIL

The source of oil and the manner in which it accumulates in rock folds has long been a problem of much interest to petroleum geologists. Lateral migration of oil to the fold in which it became trapped was for a long time a generally accepted and logical explanation. However, as knowledge of geologic factors and forces became greater these prevented the acceptance of such a universal solution of the problem and proved in some cases that its operation is impossible. To account for accumulation in many of these impossible cases, vertical migration by way of fault planes or joints was resorted to and appears to serve very well in some cases. More detailed consideration, however, revealed that this method of migration is necessarily limited. Undoubtedly lateral and vertical migration in operation, either singly or together, have caused the accumulation of oil in many cases.

The writer wishes to emphasize the possible accumulation of oil with the aid of only very local vertical or lateral migration. It may be assumed that oil originates from organic matter that was deposited with sedimentary rocks. That organic shale beds are closely associated with oil sands in many parts of

the United States is too well known to require discussion. The oil originates in these shale beds and by traveling only a very short distance accumulates in the reservoir rock.

The writer and others have collected and tested quantitatively a large number of samples from beds of organic shale from the Pennsylvanian rocks in many sections of the United States. These beds have been found from a few inches up to 15 feet thick and varying in the amount of oil they will yield by destructive distillation from $\frac{1}{4}$ to 2 barrels per ton. That such beds are thick enough and sufficiently rich to be the source of a large quantity of oil may be determined by a simple calculation. A bed 10 feet thick yielding $\frac{1}{2}$ barrel of oil per ton could be the source of oil amounting to 13,000 barrels per acre.

Regardless of the method by which the oil is formed from the organic shale beds, these data seem to show that without the aid of extensive lateral or vertical migration one or a series of these organic beds associated with a sand body may account for all the oil contained in the oil sand.

JOHN R. REEVES

OIL HILL, KANSAS

THE KIRK GAS SAND IN THE GRAHAM DISTRICT, OKLAHOMA

The Kirk gas sand is the first persistent oil- and gas-bearing zone encountered in the Graham and Fox Extension pools of the Graham district in Carter County, Oklahoma. From the description of this sand by Tomlinson and Storm[1] and the United States Bureau of Mines,[2] one is led to believe that this sand is a gas reservoir of limited areal extent—affording only salt water except on the highest parts of the structure. The Bureau of Mines concludes its description of the Kirk gas horizon by stating: "This horizon has in no instance produced oil in the Graham field. Rotary cores from this horizon have shown the presence of saturated oil sands, and have caused this sand to be mistaken for the Upper Johnson producing horizon."[3]

During a recent study of subsurface conditions in this field we have concluded that the Kirk gas sand zone is an oil-bearing as well as a gas- and water-bearing zone. According to our correlation of well logs there are a number of wells in the Graham and Fox Extension pools of the Graham district which have and are affording commercial oil production from this zone. We also found that a number of wells have been plugged back from the Johnson zone to the Kirk zone.

HENRY A. LEY

[1] C. W. Tomlinson and Willis Storm, "The Graham Field, Oklahoma," *Bull. Amer. Assoc. Pet. Geol.*, Vol. 8, No. 5, 1924.

[2] H. C. George and John R. Bunn, "Petroleum Engineering in the Fox and Graham Oil and Gas Fields, Carter County, Oklahoma," Ardmore Chamber of Commerce, 1924.

[3] *Op. cit.*, p. 13.

DISCUSSION

SOLUBLE MATERIAL IN OIL SHALE

Messrs. F. M. Van Tuyl and C. O. Blackburn, in an article recently published in this *Bulletin*,[1] determine the amount of soluble material in samples of oil shale before and after compression by grinding to an 80-mesh size and then leaching the soluble portion by solvents. The ends of a shale cylinder were cut off, ground, and tested in order to determine the percentage of soluble material before the experiment. The squeezed shale after the experiment was also ground to the 80-mesh size and tested, yielding approximately the same proportion of soluble material. I wish to point out the fact that grinding the shale to an 80-mesh size necessarily causes a greater differential movement than could possibly have been accomplished by squeezing the shale slightly in the cylinder. Consequently the experiment is not conclusive, because the grinding may have obliterated any effect the squeezing may have had if any. It can readily be observed that by continued grinding more and more leachable material can be recorded by solvents. This brings out the question whether it is merely by exposing new surfaces which were not reached by the first solution that more soluble material is available for the solvent, or whether there has been some change in the material by either heating or mechanical energy. Experiments which have been attempted to proportion the surface exposure to the solvent indicate that more material is leachable after grinding (at least for a similar time-interval) than before grinding. These are not entirely conclusive, and there is much need for considerable chemical and physical experimentation along these lines.

There is also some question as to the nature of this leachable material after passing into solution. From comparatively brief experiments, some of the residue, after solvents are evaporated, has physical properties similar to some petroleum. It has been observed to have the adhesive properties of mounting up the sides of a porcelain evaporating dish and, in a few cases, even moving over the rim of the dish. The residue appears to be a liquid, although there is considerable doubt as to its definite physical state.

A. W. McCoy

[1] Vol. 9 (1925), p. 180.

THE ASSOCIATION ROUND TABLE

MEETING OF THE EXECUTIVE COMMITTEE
TULSA, OKLAHOMA, MAY 19, 1925

The executive committee in regular session passed the following resolutions:

1. That the committee insist on the submission of manuscripts of all papers presented at the annual or semi-annual meetings of the Association and that the program committee be requested to help secure them.

2. That the arrangements for the entire program, including the entertainment for any meeting, be submitted for the approval of the executive committee.

3. That the Association accept the invitation of the members in Dallas to hold the next annual meeting in that city in March, 1926.

4. That the *Bulletin* be placed on a monthly basis the second half of the year.

5. That the Association establish permanent offices in charge of the secretary, or of an assistant secretary, who shall give essentially full time to Association matters and who shall have charge of the editorial work under the direction of the editor, the president and vice-president being empowered to put this resolution into effect.

6. That the president appoint a constitution committee to recommend such changes in the constitution as may seem desirable in the light of the contemplated changes in the conduct of the business of the Association.

7. That members dropped for non-payment of dues be re-instated only on payment of all dues for which they are in arrears.

E. DEGOLYER, *President*
R. S. MCFARLAND, *Vice-President*
J. H. GARDNER, *Retiring President*
R. C. MOORE, *Editor*
C. E. DECKER, *Secretary-Treasurer*

ERRATUM

In the list of applicants for membership which appeared in Number 5 of the *Bulletin*, the name of CRESAP P. WATSON was included by mistake in the list of applicants for full membership. It should have appeared in the list of applicants for associate membership.

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

R. A. STEINMAYER, head of the geological department of Tulane University, New Orleans, Louisiana, spent part of the summer in Shreveport familiarizing himself with geological methods and conditions in oil field work that would be useful in his courses for engineering students.

N. B. WINTER, in charge of the geological department of the Atlantic Oil Producing Company at Shreveport, Louisiana, underwent an operation for appendicitis at Highland Sanitarium in July.

H. W. BELL, supervisor of the minerals division of the State Conservation Commission, located at Shreveport, Louisiana, is preparing a bulletin on latest development in the Monroe gas field to summarize and supplement *Conservation Bulletin No. 9* which has long been exhausted and is now out of date.

J. M. WILSON, in charge of the geological department of the Simms Oil Company at Dallas, Texas, spent part of his vacation in July at Shreveport, Louisiana.

WALLACE E. PRATT, chief geologist and director of the Humble Oil and Refining Company of Houston, Texas, visited the Shreveport office of the company last July.

SIDNEY POWERS, chief geologist of the Amerada Petroleum Corporation, Tulsa, Oklahoma, attended the weekly luncheon of the Shreveport Geological Society at the Washington Hotel, Shreveport, Louisiana, July 20, and exhibited a reel of motion pictures taken on the third annual outcrop trip of the Society last June.

G. B. RICHARDSON of the U. S. Geological Survey, Washington, D.C., was a visitor in Shreveport, Louisiana, in June.

PAUL B. WHITNEY, formerly geologist for the Continental Oil Company, of Denver, Colorado, who left last January for six months' work in New Zealand, will remain another six months' period, returning to Denver in January, 1926. Exploration work is being conducted by Taranaki Oil Fields Limited, a company financed in Melbourne, Australia. Frederick G. Clapp, consulting geologist, is directing their activities and the company is now drilling two wells in Taranaki Province, New Zealand.

CARY P. BUTCHER is now geologist for the Kirby Petroleum Company, of Houston, with headquarters at San Angelo.

KENNETH B. HOWELLS has been transferred to the U. S. Bureau of Mines at Dallas, Texas.

A. K. TYSON is field geologist for the Pure Oil Company with headquarters at Mayfield, Texas.

RALPH A. LIDDLE, who has been with the Standard Oil Company in Venezuela, is now with the Pure Oil Company, Mexia, Texas.

E. A. STILLER, chief geologist for the Arkansas Fuel Oil Company at Shreveport, Louisiana, made a trip of geological reconnaissance in Mexico last June and in Montana and Wyoming last July.

O. L BRACE, who has charge of geological work for the Marland Oil Company in the Shreveport, Louisiana, territory, spent his vacation in early August with his family in the Ozark Mountains.

C. M. BENNETT, vice-president of the Louisiana Oil Refining Corporation of Shreveport, Louisiana, enjoyed part of the month of August on vacation with his family at Bella Vista, Arkansas.

G. A. KROENLEIN, chief geologist for the Gilliland Oil Company at Tulsa, Oklahoma, was in Shreveport, Louisiana, last August, examining wildcat and producing properties.

A. L. SELIG was appointed September 1 to take charge of the geological office of the Southern Crude Oil Purchasing Company, a subsidiary of the Standard Oil Company of Indiana, Slattery Building, Shreveport, Louisiana. Mr. Selig has been paleontologist with the Atlantic Oil Producing Company the past two years in the Shreveport office.

L. S. HARLOWE resigned his position as geologist with the Louisiana Oil Refining Corporation September 1, to accept a similar position with the Southern Crude Oil Purchasing Company, Shreveport, Louisiana.

C. D. FLETCHER, paleontologist with the Atlantic Oil Producing Company at Dallas, Texas, has been transferred to the Shreveport, Louisiana, office of that company.

M. A. HANNA, paleontologist with the Gulf Producing Company, Houston, Texas, visited Shreveport, Louisiana, last August, and in company with W. C. SPOONER, consulting geologist, Ardis Building, Shreveport, and F. X. BOSTICK, paleontologist, Standard Oil Company of Louisiana, Shreveport, made an extensive trip across the Cretaceous outcrop of Arkansas for the purpose of collecting type material for microscopic study.

A. F. CRIDER, chief geologist for the Dixie Oil Company, Shreveport, Louisiana, spent part of the month of August recreating with his family at Biloxi, Mississippi.

ELIOT BLACKWELDER, head of the department of geology at Leland Stanford, spent the field season in the Medicine Bow Mountains of Wyoming.

CARROLL H. WEGEMANN, R. Clare Coffin, and Ellis A. Hall of the geological staff of the Midwest Refining Company, will engage in foreign work for the Pan American Petroleum and Transport Company, with headquarters in New York City. E. L. Estabrook, formerly Petroleum Engineer for the Midwest Refining Company, is also going with the Pan American as petroleum engineer. C. Max Bauer has been appointed Chief Geologist for the Midwest Exploration Company, and will be active head of geological work in the western states.

W. HAROLD HOOTS recently received his Doctor's degree from Leland Stan-

ford Jr. University. He is engaged in work for the U. S. Geological Survey at Rawlins, Wyoming.

GEORGE H. CHADWICK will teach geology at Williams College this year during the absence of H. F. Cleland.

JAMES H. HANCE has resigned his position with the Illinois Geological Survey to become head of the department of geology in the Texas A. & M. College, College Station, Texas.

ROY HOLLOMAN has opened offices as petroleum geologist at 230 Steel Building, Denver, Colo. He is associated with Dean E. Winchester.

GEORGE R. STEVENS of the Simms Oil Company, Ricou-Brewster Building, Shreveport, Louisiana, traveled through Colorado and Nevada, visiting home folks in California during September. Mr. Stevens was accompanied by Mrs. Stevens.

SIDNEY MIX, chief geologist for the Gulf Refining Company, Shreveport, Louisiana, spent the latter part of August and early September with his family at Lilly Dale, New York.

C. E. DECKER spent the summer at Ithaca, N. Y., where he taught in the summer session of Cornell.

W. T. THOM JR. has been at work during the summer with various field parties of the U. S. Geological Survey in western states.

N. W. BASS, of the U. S. Geological Survey, was engaged in geological work near Steamboat Springs during August and studied the Wray, Colorado, gas field early in September.

WILBUR NELSON has resigned his position as state geologist of Tennessee to become state geologist of Virginia and head of the department of geology of the University of Virginia.

D. DALE CONDIT, with Mrs. Condit, passed through Denver during July and spent several days visiting old friends. Mr. Condit was formerly with the U. S. Geological Survey and has for five years been in charge of geological work in India for the Whitehall Petroleum Corporation, Limited, of Great Britain. He returns to this work at the termination of his vacation. Mr. and Mrs. Condit have climbed some 17,000-foot peaks in the Himalaya Range and brought back some remarkable photographs of the Himalayas and the Vale of Cashmir, as well as of the jungles of Burma and southern India.

FRANCIS M. VAN TUYL spent most of the summer at the Colorado School of Mines, Golden, Colo., in experimental laboratory work in petroleum geology.

GEORGE V. DUNN has resigned from the Roxana Petroleum Corporation to accept a position with the Union Oil Company of California. He is now living in Long Beach, California.

H. D. MISER has been appointed state geologist of Tennessee for one year, beginning September 1, 1925.

PROFESSIONAL DIRECTORY

ADDRESS: WILLIAM B. HEROY, ADVERTISING MANAGER, ROOM 1500,
45 NASSAU ST., NEW YORK CITY

D. DALE CONDIT

CHIEF GEOLOGIST IN INDIA

WHITEHALL PETROLEUM CORPORATION LTD.
SHILLONG, ASSAM, INDIA
AND
53, PARLIAMENT STREET, LONDON, S.W. 1
(NO OUTSIDE WORK)

HUNTLEY & HUNTLEY

PETROLEUM GEOLOGISTS
AND ENGINEERS

L. G. HUNTLEY — STIRLING HUNTLEY

FRICK BUILDING, PITTSBURGH, PA.

R. A. CONKLING

CONSULTING GEOLOGIST
PETROLEUM ENGINEER

COLCORD BUILDING — OKLAHOMA CITY, OKLA.

GEO. C. MATSON

GEOLOGIST

408 COSDEN BLDG. — TULSA, OKLA.

JAMES L. DARNELL

ENGINEER

170 BROADWAY — NEW YORK CITY

DABNEY E. PETTY

ASSOCIATE GEOLOGIST

BUREAU OF ECONOMIC GEOLOGY
AND TECHNOLOGY

AUSTIN - - - - TEXAS

RALPH E. DAVIS

VALUATION ENGINEER

902 PEOPLES GAS BLDG., PITTSBURGH, PENNSYLVANIA

DEWITT T. RING

GEOLOGIST

404 ARMSTRONG BLDG. — EL DORADO, ARK.

FRANK W. DeWOLF

CHIEF GEOLOGIST
HUMPHREYS CORPORATION

NOT OPEN FOR CONSULTING ENGAGEMENTS

501 MASON BUILDING — HOUSTON, TEX.

EUGENE WESLEY SHAW

GEOLOGIST

170 BROADWAY — NEW YORK